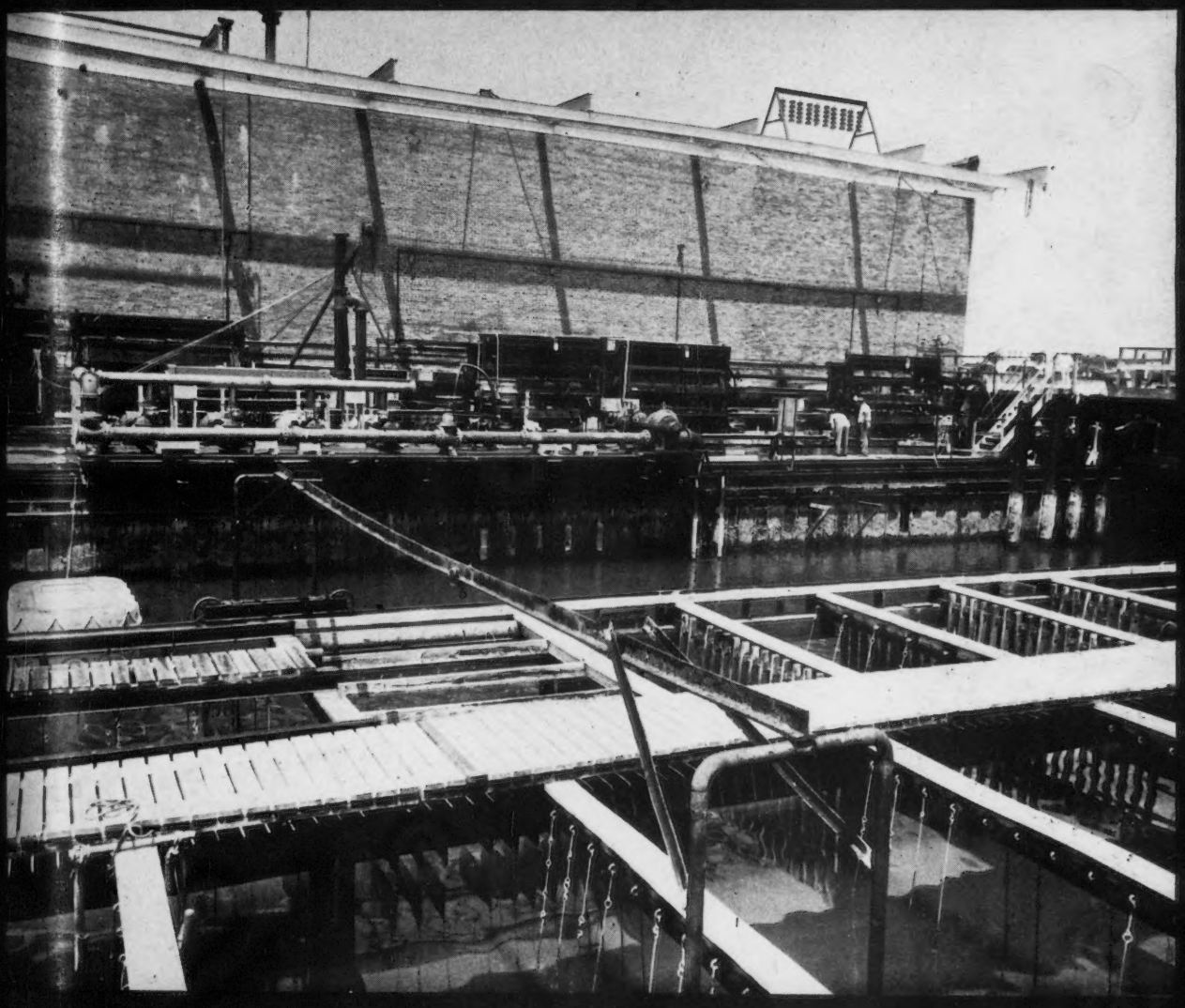
Corrosion



CORROSION COSTS INDUSTRY

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ANNUALLY!

How much do you pay?

FOLLOW THE LINE OF *most* RESISTANCE

A SYSTEM OF SURFACE PROTECTION

Don't risk needless waste

If all corrosion were as obvious as it is in steel pipe, industry would do more about it. But it is not. Often hidden or unnoticed — indoors and outdoors, above ground and below ground — corrosion takes its daily toll. Acids, alkalis, salts, gases and atmospheric conditions all are contributing factors. As a result, industry pays a terrific bill for corrosion — far more than it should. Your own cost, too, may be greater than necessary. Minimize your risk — do these two things now —

1. *Check up on your costs;*
2. *Provide adequate protection for danger points.*

Experienced and competent AMERCOAT engineers are available to help you on both. They'll check up on your costs, which may be greater than you know because the effects of corrosion are often hidden. They'll report on conditions as they find them. They'll recommend steps to take if greater protection can be provided and money saved. Inquiries from interested executives will receive prompt attention. There's no obligation — write today.

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"PUTTING Permanence IN PIPE"
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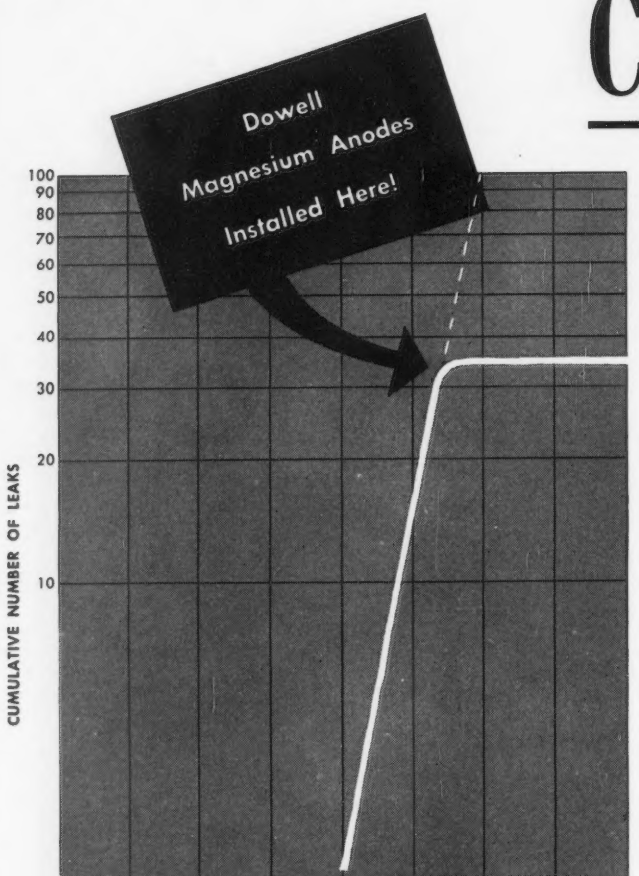
22 YEARS DOING ONE JOB WELL

Here's How . . .

PIPELINE MAINTENANCE COSTS CAN BE CUT!



One way to lower pipeline maintenance costs is to reduce the number of leaks. The graph at left shows how a Gulf Coast city cut leaks in a 27 block, 2″ galvanized piping system. The system was installed in 1940 and 1941. By April, 1946, leaks were appearing at an accelerated rate. *Then, magnesium anodes were installed!* Result: 2 leaks in the 30 days following installation and *no new leaks for the balance of 1946, 1947 and 1948!*

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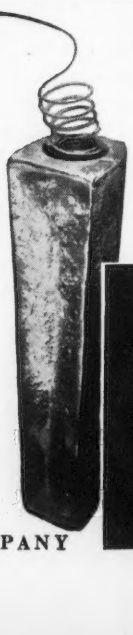

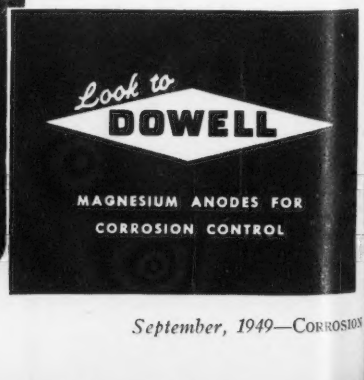

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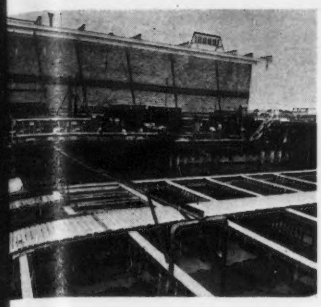

MONTH'S COVER—This view of the sea immersion test basin shows platforms giving access to the racks from which specimens are suspended in the water, and in the background a full-scale heat exchanger test setup as well as other testing arrangements at Kure Beach, North Carolina.

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Corrosion

devoted entirely to

CORROSION
Research and Control

Published monthly as its official journal, by the National Association of Corrosion Engineers, Inc., at Houston, Texas, U. S. A., to provide a permanent record of progress in the control of corrosion as described in papers prepared for the Association and from other sources.

VOL. 5 SEPTEMBER, 1949 No. 9

CONTENTS

Directory of NACE Regional and Sectional Officers iv
Technical Committee Activities—New Developments in Protective Coatings xv

TECHNICAL SECTION

Engineering Aspects of Cathodic Protection as Applied to Pipe Lines
By E. P. Doremus, G. L. Doremus and M. E. Parker, Jr. 273
Corrosion Resistance of Sprayed Metal Coatings
By Walter B. Meyer 282
An Investigation of Structural Steel Shop Coat Priming Paint
By S. C. Frye 288
Cathodic Protection of Steel Piling in Sea Water
By H. A. Humble 292
Discussions: By G. C. Cox, Page 300. By C. P. Larrabee and F. L. LaQue, Page 301.
Corrosion Testing Facilites at Kure Beach, North Carolina
By Ivy M. Parker 303
A Method for Activating Stainless Steel Specimens Prior to Corrosion Tests
By R. O. Bayer and E. A. Kachik 308
Discussion: Methods for Preventing Rust in Water Tanks
By J. L. Gilliland, Jr. 310
NACE Technical Practices Committee Reports
Sub-Committee TP-12—Electrical Grounding Practices 311
Topic of the Month—Multi-Layer Insulation Applications Include Non-Capillary Glass Fabric 313

CORRELATING COMMITTEE ON CATHODIC PROTECTION

Bulletin II—Cathodic Protection Notification Procedures 2
Bulletin IV—Joint Cathodic Protection Systems 7

NACE NEWS SECTION

NACE Membership Increases 30 Percent 10
NACE Calendar 11
Ballots on Articles Changes Counted 11
Corrosion Will Publish Membership List Changes 11
Reports of Technical Practices Sub-Committees Being Collected 11
Mudd and LaQue to Speak On Basin Tour Program 11
Five Named to 1950 Conference Symposia 12
South Central Region Program Distribution Scheduled 12
TP Reports Numbering System Is Outlined 12
Electrochemical Society Corrosion Division Symposium Set 13
NACE New Members and Address Changes Listed 13
New Products, Materials, Services, Literature 14

CORROSION ABSTRACT SECTION

	Page		Page
Coatings	16	Inhibitors	28
Fundamentals	16	Inspection	32
General	24	Metal Failure	37

Index to Advertisers 40

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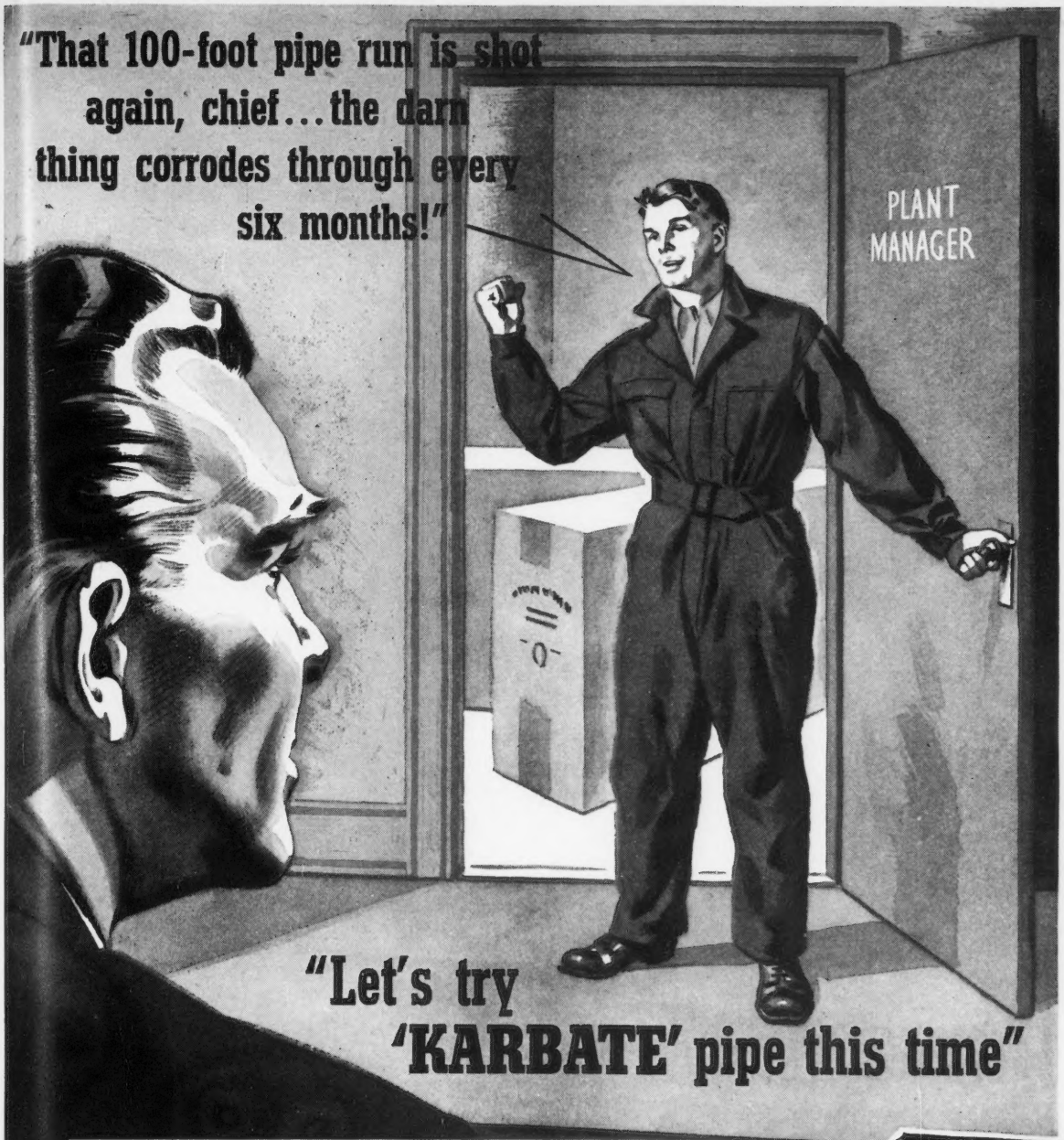
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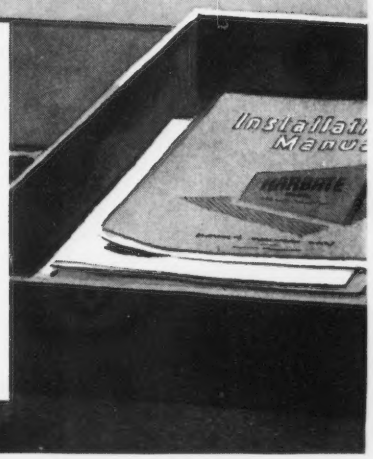

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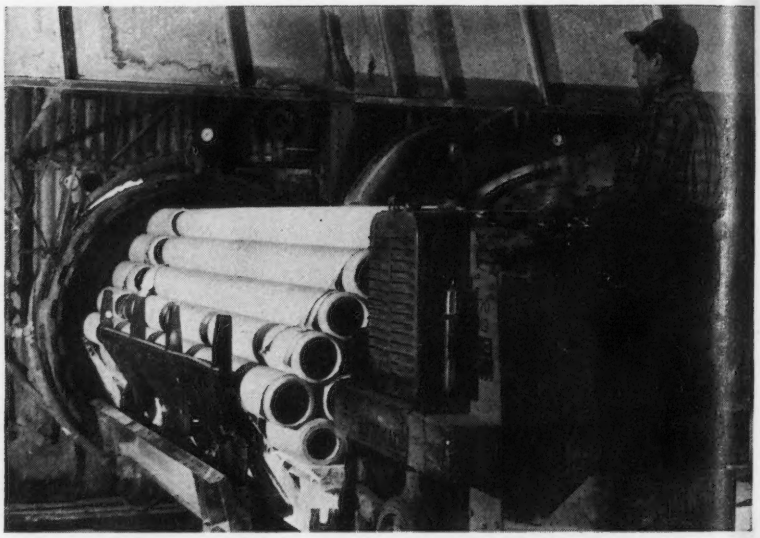
Ability to withstand corrosion is the most important single measure of the durability or life expectancy of an underground water pipe material. Two factors—both inherent in the pipe itself—contribute to Transite's exceptional ability to resist corrosion. These are:

1. The inherently corrosion-resistant materials of which Transite is made.

2. The specially developed manufacturing process — employed exclusively by Johns-Manville—which imparts a high degree of chemical stability to the finished product.



A load of Transite Pipe about to enter the steam curing tanks. This step in the Johns-Manville manufacturing process contributes substantially to the corrosion resistance of the finished pipe—and, therefore, to its long service life.

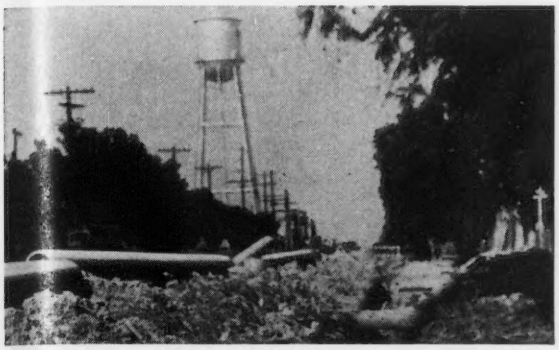
In the manufacture of Transite Pipe, the three basic ingredients, asbestos fibres, cement and silica —all basically corrosion-resistant by nature—are consolidated under tremendous pressure to form a pipe wall of dense, uniform, homogeneous structure. After forming, the pipe is subjected to a special steam curing process.

It is in this steam curing stage that so much is contributed to the stability and structural integrity of the pipe. Here under the action of pressure steam, Transite assumes a new chemical identity. The silica unites chemically with the free lime ordinarily associated with cement products and converts it into highly stable calcium silicates. As a result of this process, the cured pipe is unusually resistant to corrosive attack throughout its entire structure.

Transite Pipe was first used by this large west coast city in 1933. Its exceptional corrosion resistance—an index of long life—has already made it possible for Transite to outlive other pipe several times over.

*Transite is Johns-Manville's registered trade mark for its asbestos-cement pipe and other products.

This intrinsic resistance to corrosion has been substantiated by numerous Transite installations. Some of these have been exposed to highly aggressive soils, both alkaline and acid, for many years. Many are now serving as replacements under conditions so destructive that the useful life of the pipe materials previously used had been seriously curtailed.



Transite Pipe was installed in this Texas city ten years ago to replace another pipe material that had been destroyed by soil corrosion in 7 years. The Transite mains are still on the job today with a long useful life ahead of them.

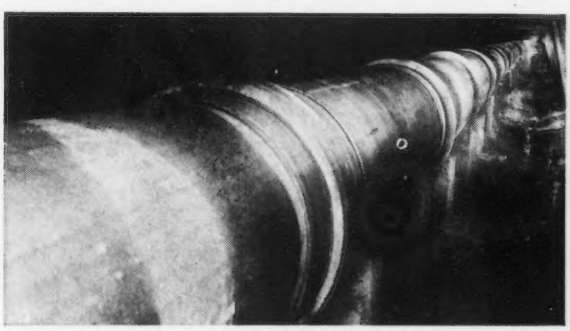
In one such installation, a Transite main installed during 1932 in an extremely corrosive soil was recently made the subject of careful study to determine its condition. Sections of the pipe, including couplings, were dug up and shipped to the factory for test. There was no evidence of deterioration. Pipe and couplings readily withstood the original factory pressure test, equivalent to four times the normal working pressure of the line.

Like thousands of other communities, this West Virginia city selected Transite Pipe because it promised assurance of maximum life. Today, after 14 years of service, the first installation of Transite has already fulfilled this promise by outlasting the pipe material previously used.

Certain types of industrial service provide an even more severe "proving ground" for the life expectancy of pipe materials, and here, too, Transite Pipe has demonstrated exceptional corrosion resistance. Coal mine service is a typical example. Here acid mine waters are frequently so corrosive that they have destroyed ordinary pipe materials in a matter of a few months or years. Yet Transite Pipe has handled these same waters under working pressure up to 150 lbs. for periods from 10 to 15 years with little, if any, indication of deterioration.

Corrosive soil conditions were so severe at this location in a prominent New England city that the life of the pipe material formerly used was only 15 years. Transite Pipe, put in as a replacement in 1934, continues to give the same efficient, dependable service as the day it was installed.

To evaluate the ability of pipe materials to withstand soil corrosion, the National Bureau of Standards has conducted an extensive series of field tests. These studies are based on examination of hundreds of pipe samples periodically removed from severely corrosive soils. In these and similar tests, Transite Pipe has consistently demonstrated its superior resistance to soil corrosion, confirming the long life expectancy which this asbestos-cement pipe has evidenced in thousands of water works installations.



Transite's ability to provide long-term, dependable service is well illustrated by its performance in coal mines, where it consistently outlasts other pipe materials in carrying corrosive mine drainage waters. The 36" Transite line shown above has been conveying acid mine waters for 15 years.

For further details about Transite Pressure Pipe, write Johns-Manville, Box 290, New York 16, N. Y.

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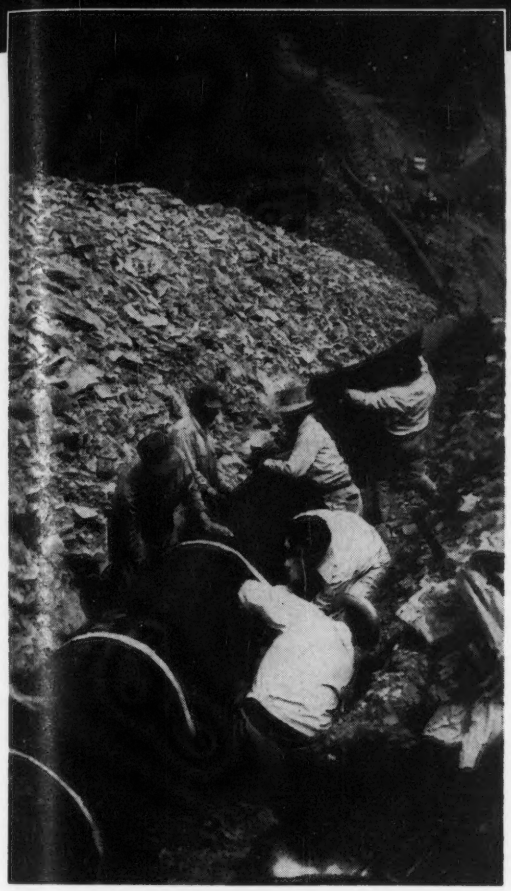

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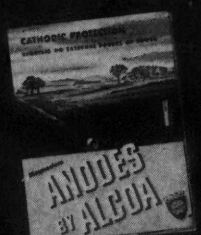

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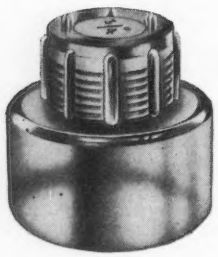

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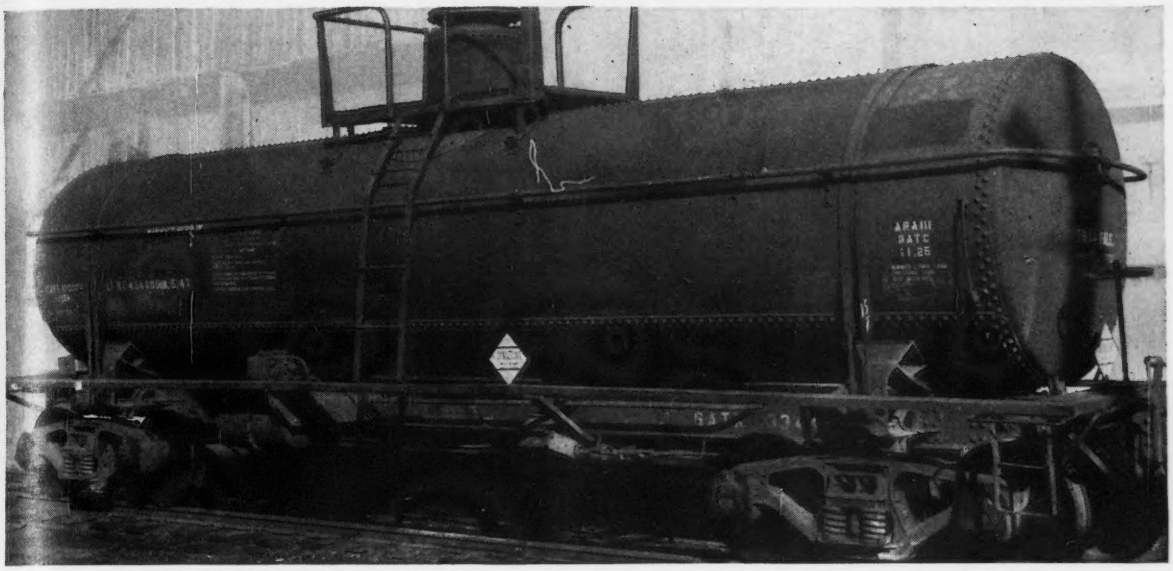

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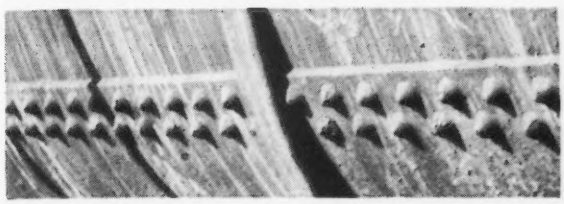

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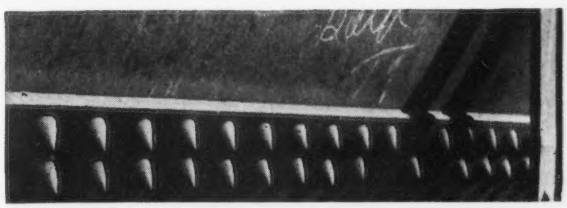

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INCO Technical Service reviewed all reports on magnesium chloride which were contained in the Corrosion Data File.

A comprehensive summary of this information was sent to the producer. (He later requested additional copies for members of his staff.)

Space limitations make it impossible to give complete details of the summary here.* The principal conclusions drawn were:

1. Corrosion rate of Inconel in relatively air-free solutions of hot magnesium chloride will ordinarily be less than 1 mdd.
2. Inconel is usually not subject to pitting below the liquid level.
3. Inconel is not subject to stress corrosion cracking.
4. In air-free solution under vacuum, Monel showed a corrosion rate of 2 mdd.
5. Ni-Resist and 30% nickel cast iron have sufficient corrosion resistance to be useful materials for pumps and valves.

The producer installed Inconel equipment with considerable success.

**Copies of the full summary, exactly as furnished this producer, are available. If you'd like one, use the coupon at the right.*

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New Developments in Protective Coatings

By KENNETH TATOR*

Four classes of tools are employed by the corrosion engineer: Corrosion-resistant metals, cathodic protection, corrosion inhibitors, and protective coatings and linings. The latter is the field of Technical Practice Committee No. 6—Protective Coatings.

While this committee has been in existence for a number of years, prior to April 1949 its activity was that of reference and co-ordination. On that date new objectives were established and the committee has since been expanding to better attain those objectives.

The objectives, their raison d'e'tre, and the committee approach is the subject of this report.

For our purposes, protective coatings and linings may be defined as continuous inert barriers interposed between the load-bearing corrodable metal and the corrosive environment, which are adherent and conforming to the surfaces of that metal. Thus are included organic coatings and linings, glass and vitreous enamel linings, and coatings of resistant metals deposited by electroplating, hot dip, or metal spray. Resistant-metal clad steel comes within our definition, but are most properly assigned to those Committees dealing with corrosion metallurgy. Passive protective films formed by inhibitors or other causes fail through lack of inertness to fall within this definition or committee responsibility, as such conversion coatings may be destroyed and reformed by changes in type or concentration of corrodent, or in current density.

Within this broad definition of committee responsibility, directness of attack has been accomplished by first subdividing the committee according to class of protective material. A number of sub-committees, discussed later, have been set up to deal with various aspects of organic coatings and linings. Sub-committee 6H—Glass and Vitreous Enamel Linings, G. H. McIntyre, Chairman, is at work preparing a system of classification of the various types of glass, vitreous and porcelain enamel coatings, and specifications, descriptions, properties and limitations of each for chemical process equipment, architectural uses, and product protection. Sub-Committee 6I—Metallic Coatings can be activated as need arises.

* Kenneth Tator of Kenneth Tator Associates, Coraopolis, Pa. Chairman of Technical Practice Committee No. 6 on Protective Coatings.

Protective organic coatings and linings range from the relatively thin paint films to heavy duty sheet linings. For the relatively mild, but exceedingly costly, corrosion from atmospheric exposures, selected standard products of the paint and varnish industry are usually adequate, and this industry is active in its development of improvements. It is not the intent of Technical Practice Committee No. 6 to duplicate the long and fruitful activities of the various paint and varnish technical associations. On the contrary we wish to direct information assembled by these to the solution of our professional problems. This is being done through Sub-Committee 6B—Protective Coatings for Resistance to Atmospheric Corrosion, G. G. Sward of the National Paint, Varnish and Lacquer Association, Chairman. In a similar approach Sub-Committee 6C—Protcetive Coatings for Resistance to Marine Corrosion, R. P. Devoluy, Chairman, is proceeding with an evaluation of the basic film forming organics as barriers against marine corrosion.

Beyond these atmospheric and marine applications where certain standard products of the paint industry often have proved adequate the NACE through Technical Practice Committee No. 6 has embarked into a new fast-growing field, which is neither served nor represented by any other organization.

This is the field of coatings for resistance to aggravated or severe corrosion attack such as chemically active corrodents, sustained galvanic corrosion, or corrosion accompanied by abrasion, erosion, or impact. For these services the usual paint film is inadequate. Within recent years rubber linings, long and successfully used, have been augmented by a long list of new polymers. The formulation and application of these has been the foundation of a new and growing industry.

As is true of any young industry, no standards of nomenclature, testing procedures, quality or performance have yet been established as a guide for these manufacturers and applicators. That this industry is looking to NACE for such guidance is evident from their wholehearted support and work on Technical Practice Committee No. 6, and in their participation at the 1949 NACE annual meeting:

> 14% of the total registration were associated with companies specializing in the manufacture or application of protective coatings (of the four methods of corrosion control, equalled only by members of the corrosion-resistant metals industry).
>
> 33% of the exhibitors were from this industry (far exceeding exhibits of the other three methods of corrosion control).

That corrosion engineers are looking to NACE for reliable information regarding the potentialities and limitations of these materials was evidenced by the over-capacity attendance at the Protective Coating Symposium and the Technical Practice Committee No. 6 meeting.

Sub-committee 6A—Organic Coatings and Linings for Resistance to Chemical Corrosion, Kenneth Tator, Chairman, is functioning to provide reliable performance data on each of the organic materials now in successful use. Sub-Committee 6G—Surface Preparation for Organic Coatings, A. J. Liebman, Chairman, is preparing guide recommendations for the most economical preparation for successful application of these materials. Sub-Committee 6J—Standards, G. G. Sward, Chairman, is the reference body for recommendations of uniform standards of nomenclature and procedures.

A number of major industries have coating requirements and conditions peculiar to that industry, and attention is given to these through Sub-Committee 6F—Protective Coatings in the Food Industries, G. W. Seagren, Chairman, dealing with taste, color, and toxicant-free materials; Sub-Committee 6D—Pipeline Coatings, and Sub-Committee 6E—Protective Coatings in Petroleum Production, to follow and summarize the performance of the various protective coatings for line pipe, sour crude stock tanks, sucker rods, and the like.

On completion of this admittedly ambitious program, each of the protective coating types will be clearly identified, and reliable performance data, application recommendations, and the limitations of each will be readily available.

THE NATIONAL ASSOCIATION OF CORROSION ENGINEERS

is a non-profit, scientific and research association of individuals and companies concerned with corrosion or interested in it, whose objects are:

(a) to promote scientific research in determining the causes of corrosion and methods of its control with respect to theory and practice.

(b) to provide a means of exchange of knowledge and ideas among those individuals actively engaged in the control of corrosion.

(c) to promote methods of control of corrosion.

(d) to promote standardization of terminology, methods, equipment and design in the development of methods of corrosion control.

(e) to foster cooperation between individual owners of metallic structures in the solution of their joint corrosion problems.

It is an incorporated association without capital stock, chartered under the laws of Texas. Its affairs are governed by a Board of Directors, elected by the general membership. Officers are nominated by (1) the Board of Directors, or (2) a quorum of at least 25 members, and elected by the membership.

Inquiries regarding membership, and all general correspondence should be directed to the Executive Secretary at the administrative headquarters of the National Association of Corrosion Engineers at 919 Milam Building, 803 Texas Avenue, Houston 2, Texas.

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Engineering Aspects of Cathodic Protection As Applied to Pipe Lines*

By E. P. DOREMUS,* G. L. DOREMUS* and M. E. PARKER, JR.*

THE ECONOMIC PROBLEM in the cathodic protection of pipe lines is, in the case of an existing line, that of comparing the costs of (1) complete cathodic protection, with indefinite extension of pipe life and high salvage value; (2) partial protection, with some extension of life and a lower salvage value; (3) reconditioning of the line, with lowered costs for complete cathodic protection; or (4) some combination of these considerations. In the case of a new or planned line, the problem is largely that of balancing costs of coating and cathodic protection; the best coating is not quite good enough without cathodic protection, but even poor coating reduces the cost of protection far below that for a bare line. For each particular line, the economic balance between these two costs must be determined.

The **Engineering** problem in cathodic protection is that of designing, for a given line, a system of electrical protection which will afford the desired degree of protection at minimum cost, calculated over the projected life of the pipe, without spending too much on engineering. Frequently such a design must be made in the form of an estimate, in order to furnish data needed for the economic decisions discussed above. The most common problem of the Corrosion Engineer, however, is that of designing a system to provide complete cathodic protection for an existing line, i.e., one which will prevent current from leaving the line at any other than the preselected drainage points. Any current which flows to any part of the line in excess of the quantity needed to achieve this condition is wasted, and it must be decided how much such excess can be justified by the economies incident to the installation of a system less complex than the one which would supply the ideal minimum current. It is with this problem of designing for complete protection that this paper is principally concerned.

There are three generally recognized criteria for complete protection; one based on current density, one on potential, and one on the current-potential relation. The last mentioned has the soundest basis in electrochemical theory,[1] but is cumbersome and slow in application. Briefly, it consists of applying a set of increasing values of current, and measuring the pipe-to-soil potential for each value. When this latter reading is corrected for the IR drop in the soil between the pipe and the reference electrode (a correction requiring a somewhat complex instrumentation and procedure) it is found that, as the lower values of current are applied, the potential remains constant; when the current exceeds a certain critical value, however, the potential begins to increase in proportion to the logarithm of the current. This critical value of current is that which just barely establishes protection—as has been well established by theory and experiment. Figure 1-A shows a typical set of such values, plotted on semi-logarithmic paper. If the potential of the pipe is merely measured with respect to a reference electrode, with no attempt to eliminate or correct for the IR drop, the potential will rise with each increase in current, as shown in

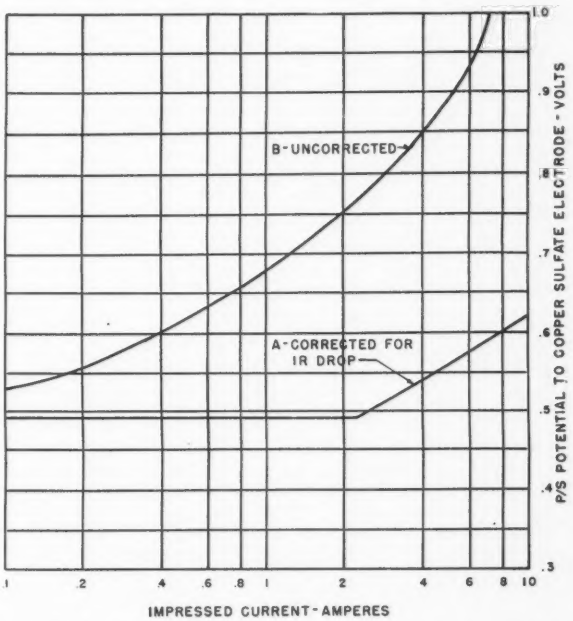

Figure 1—Break in current-potential curve as a criterion for the establishment of Cathodic Protection on Pipe Lines.

★A paper presented at the Fifth Annual Conference, National Association of Corrosion Engineers, Cincinnati, Ohio, April 11-14, 1949.

*Cathodic Protection Service, Houston, Texas.

Figure 1-B, thus masking the sought-for effect. The full correction technique, involving synchronized changes in current values at one point on the line and potential readings at another, followed by calculations and curve-plotting, culminates in a very precise determination of the protection requirements of the pipe at **one** point. It is easy to see why it has not found very wide application except as a research procedure.

The criterion based on current density, without reference to potential, attempts to establish a certain value of current per square foot of surface which will be adequate for protection in a given corrosive exposure. Research has indicated values ranging from 1 to 12 milliamperes per square foot required to protect steel in various natural soils and waters. This wide range, combined with the difficulty of estimating the equivalent of a coated pipe in terms of bare metal, makes this a very difficult criterion to apply. It is highly useful, however, as a guide in estimating the current requirements of lines prior to actual field tests.

A study of numerous curves like those in Figure 1 indicates that in almost every instance an uncorrected pipe-to-soil potential, referred to a copper sulfate electrode, of —0.85 volt is well past the break in the curve, but not far enough past it to lead to much wasted current. The adequacy of this potential is further demonstrated by the actual stoppage of leaks —and there can be no better criterion of protection —on lines on which it has been maintained. Since this uncorrected potential requires but a single simple reading at each location, no synchronized operations, and no calculations, it has become by far the most commonly used criterion for the cathodic protection of steel and iron in soils and waters. The authors have adopted this criterion in their own work, and it is used exclusively in the following discussion.

Since the current drain required to produce —0.85 volt over the length of the bare or spot-coated line is quite high, complete protection may not be the most economical approach to the problem. In such cases partial or "hot-spot" protection may provide 80 to 90% of complete protection with only 10 to 20% of the current and 15 to 25% of the cost for complete protection. The anodic (corroding) areas may be located with varying degrees of precision by (1) a study of leak records, (2) a soil resistivity survey, or (3) line current measurements with location of the major points of polarity change. By discarding the —0.85 volt potential criterion for this type of installation, a greater proportionate part of the total cost of cathodic protection is spent for engineering, with a resultant lowered over-all cost. A discussion of the techniques of partial protection lies outside the scope of this paper.

In the case of a line with continuous coating, even though it may be in relatively poor condition, the savings which may be effected by properly distributed partial protection are more than offset by the additional cost of the engineering involved. Hence, such a line is most economically protected by bringing the full length of the line to —0.85 volt potential. It should also be mentioned that the cost of reconditioning an **existing** poorly coated line, plus the cost of subsequent cathodic protection at reduced current requirements, will in general be several times the cost of providing complete cathodic protection for the line in its poorly coated condition, based on an anticipated operating life of thirty years for the line.

To recapitulate, the design problem to be considered here, is that of devising a system which will drain current from a given pipe line in such quantities and at such spacings as to bring every point of the pipe to a minimum potential of 0.85 volt negative, measured with reference to a copper sulfate electrode. This will require a study of the amount of current required to produce this potential by different systems, in amperes per mile, and the cost of current by different systems, in dollars per ampere, in order to arrive at minimum protective costs in dollars per mile —all considered in terms of profitable pipe life.

When cathodic protection is applied to a coated line, there is an upper limit to the potential to which the pipe can be raised, in order to avoid damage to the coating and excessive over-protection at the drain point. This is usually considered to be —2.5 volts to a copper sulfate electrode. This sets a limit to the amount of current which can be drained from a single point, a limit which depends on the pipe size, the completeness and effectiveness of the coating, and the electrical resistivity of the soil. When this maximum current is drained from a point, the pipe-to-soil potential is a maximum at the drain point, and decreases exponentially along the pipe in both directions.[2-3] The rate at which this attenuation takes place also depends on the pipe size, soil resistivity and the coating on the pipe. It is very strongly influenced by coating, being very steep for bare or poorly coated pipe, and relatively flat for pipe with good coating; the ratio may easily be as great as 1000 to 1. Figure 2 shows typical decay curves for two 8" lines in similar soils, one bare, and the other with a rather poor coating. It will be seen that on the bare line (curve A) 175 amperes protects 9,200 feet of line, while on the coated line (curve B) 25 amperes protects 64,000 feet of line.

In protecting an entire line, however, the units may be placed further apart, so that at a midpoint the combined effect of the two adjacent drainage points will afford protection. Figure 3 shows this arrangement for the same two lines placed on different diagrams because of the difference in spacing. This total protection requires a drainage of 175 amperes every 12,400 feet for the bare line (Figure 3-A) a current demand of 74 amperes per mile, and a drainage of 25 amperes every 88,000 feet for the coated line (Figure 3-A) a current demand of 1.5 amperes per mile. The power expended in raising the potential above 0.85 volt can only be regarded as wasted power; anything that can be done to decrease this waste will result in **current** economy, although we shall have to be careful to examine to see if it also represents **dollar** economy.

If a smaller amount of current is drained from each point the potential at the drain point will be lower and

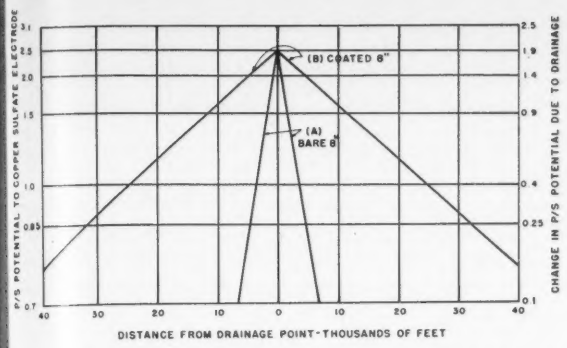
(B) COATED 8"
(A) BARE 8
P/S POTENTIAL TO COPPER SULFATE ELECTRODE
CHANGE IN P/S POTENTIAL DUE TO DRAINAGE
DISTANCE FROM DRAINAGE POINT-THOUSANDS OF FEET

Figure 2—Attenuation curves for (A) bare 8" steel pipe and (B) poorly coated 8" steel pipe in similar soils.

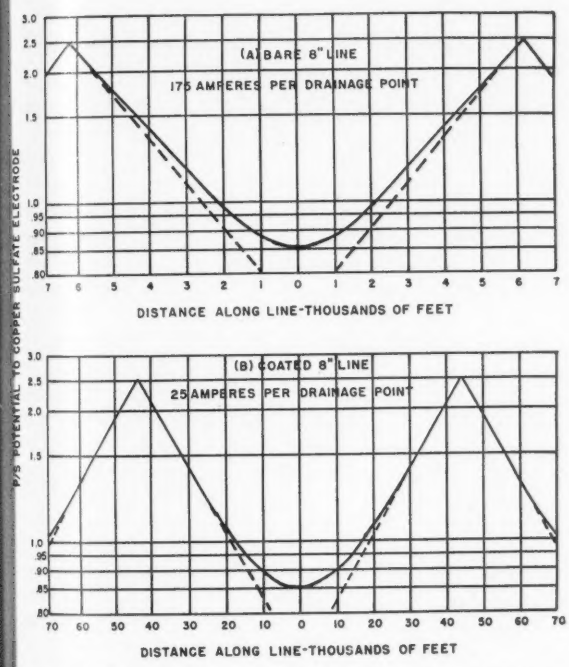
(A) BARE 8" LINE
175 AMPERES PER DRAINAGE POINT
(B) COATED 8" LINE
25 AMPERES PER DRAINAGE POINT
P/S POTENTIAL TO COPPER SULFATE ELECTRODE
DISTANCE ALONG LINE-THOUSANDS OF FEET

Figure 3—Combined attenuation curves for large multiple drainage points.

less power will be wasted per unit. This will of course necessitate a closer spacing of the drainage points, but the net result is a considerable decrease in total current demand. Figure 4 shows the effect of more closely spaced smaller units on the same two lines. The bare line requires 40 amperes every 6,100 feet with a total current demand of 35 amperes per mile (Figure 4-A). The coated line takes 8 amperes every 53,000 feet, total current demand 0.8 amperes per mile (Figure 4-B).

As this process is carried further, reducing the spacing between drainage points causes a reduction in current needed per drainage point which is greater than the reduction in spacing. A new factor comes into the picture; the potential at a given point has to be considered as made up of the contributions of the two immediately adjacent drainage points, plus a somewhat smaller contribution from the next most distant pair, and so on, adding successively smaller contributions from successively more distant drainage points. Except for the very simple case of a uniformly coated (or totally bare) line in perfectly uniform soil, protected by a set of equally spaced drainage points draining identical amounts of current, the mathematical analysis of this cumulative effect is extremely complex; but such studies,[4] and actual field experience, agree in demonstrating that any long line can be protected by means of a large number of small drains with far less total current than with a small number of heavy drains. This is true for any line, bare or well coated, in either high or low resistivity soil, uniform or variable. As the spacing between drainage points is decreased, the current required per drainage point decreases at a greater rate, with the result that the total current demand per mile decreases; rapidly at first, then more and more slowly, until finally a point is reached where there is little to gain by closer spacing. The value of current per drain point, as well as the spacing required, is quite different for different lines. Figure 5 shows the change in current demand per mile and current per drainage point, as the spacing is decreased, for the same two lines previously discussed. Both curves are based on just reaching full protection at the midpoints.

Figure 6 shows the variation in current demand with the size of the individual drainage points, for the same two lines. It will be seen that for each line a point is reached beyond which no saving can be effected in total current requirement by further decrease in current per drain point. Further reduction with correspondingly closer spacing, might, however

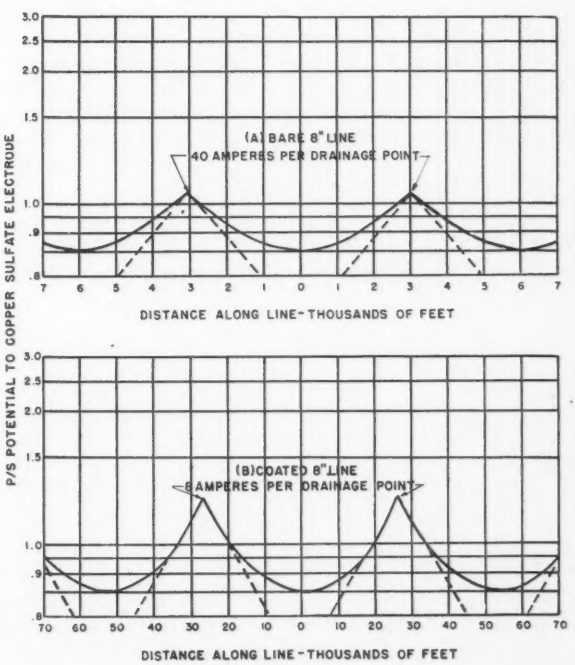
(A) BARE 8" LINE
40 AMPERES PER DRAINAGE POINT
(B) COATED 8" LINE
8 AMPERES PER DRAINAGE POINT
P/S POTENTIAL TO COPPER SULFATE ELECTRODE
DISTANCE ALONG LINE-THOUSANDS OF FEET

Figure 4—Combined attenuation curves for multiple drainage points of moderate size.

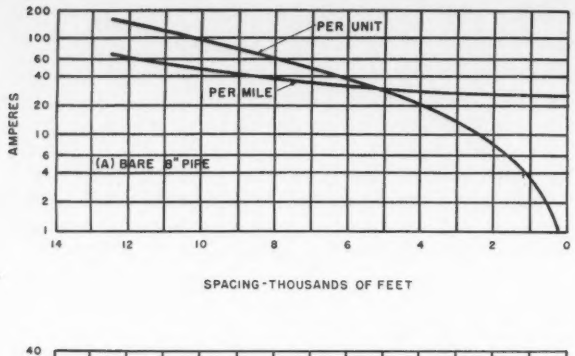

Figure 5—Variation of current requirements and drainage point size with spacing.

be dictated by the limitation placed on anode group size by soil resistivity.

It should be emphasized that the data in Figures 5 and 6 are based on anodes remote from the pipe line. The actual distance off the pipe line necessary to approach the ideal conditions assumed in the preparation of the curves depends primarily on the size of the drain point and the effective resistivity of the pipe coating, if any. It will vary from a few feet for currents on the order of 1 ampere on well-coated lines, to four or five hundred feet for 10 amperes on a bare line. Location of anodes closer to the pipe will result in an unduly high potential shift and an unduly high current concentration in the immediate vicinity of the anode location.

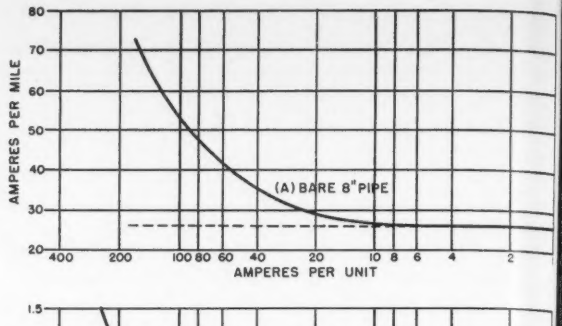

Figure 6—Decrease in current required for protection with decrease i size of unit.

The above comparisons of current requirements are based on mathematical analyses; that these correlate closely with actual experience is illustrated in Figures 7 and 8. Figure 7 presents graphically the pipe-to-soil potentials taken over the length of an isolated 13.6 mile section of 8″ pipe line with a twenty year old pitch type coating, during forced drainage of current from (a) a number of magnesium anode groups placed on one-half to two mile spacing and draining 0.59 to 3.15 amperes each, and (b) a test generator draining 60 amperes from a single point. In both instances the line had been completely polarized. The current drain from the single point was limited as described above, so as not to produce a pipe-to-soil potential in excess of 2.5 volts. It will be noted that a total current of 14.4 amperes by the distributed magnesium anode groups was ample to provide complete protection of the entire line. On the

TABLE I
MAGNESIUM ANODE—CATHODIC PROTECTION INSTALLATION ON 13.6 MILES OF 8″ COATED PIPE LINE

Inventory Station No.	Anode Station No.	Pipe-to-Soil Potential* Before	Pipe-to-Soil Potential* After	Total Current Output (Amps.)	Number and Size of Anodes	Output per Anode (m.a.)	Projected Life (Years)
232+70	1	0.63	0.98	1.67	6—5-A 3—1-A	248 60	12.4
244+00	midpoint	0.63	0.94				
271+70	2	0.64	1.04	1.32	5—5-A	264	11.3
313+20	midpoint	0.63	0.90				
352+37	3	0.62	0.92	1.15	5—5-A	230	12.9
407+59	midpoint	0.62	0.85				
458+00	4	0.62	0.91	3.03	12—5-A	253	11.7
536+94	5	0.63	0.85	0.59	2—5-A	295	10.0
639+40	6	0.65	1.08	2.17	9—5-A	241	12.3
694+40	midpoint	0.64	0.92				
749+10	7	0.64	1.08	3.15	35—1-A	90	10.1
830+00	midpoint	0.63	0.87				
917+05	8	0.66	1.08	1.35	5—5-A	270	11.0
Total Current Output All Stations (amps.)				14.43			

* Note: Volts negative referred to remote copper sulphate electrode.

other hand, the drainage of 60 amperes from a single point failed to bring the whole length of the line up to the point of complete protection. The maximum potential reached by the distributed magnesium anode system was only 1.1 volts to a remote copper sulfate electrode, i.e., one placed over the line 100′ from the drain point. The current drain and pipe-to-soil potentials at each of the several anode stations is presented in Table I.

Figure 8 presents similar data on a 33 mile 8″ asphalt coated line. The curve for the heavy drain points is based on a test made at one point only; a welding machine was used to drain current to a temporary ground bed. The dotted portions of the curve are based on the assumption that the remainder of the line has similar characteristics. The curve for the distributed magnesium anode groups represents the final potential curve for a complete cathodic protection installation. Total drain for the magnesium anodes was 75.4 amperes. This contrasts with a projected requirement of 300 amperes from five 60-ampere rectifiers, if indeed power availability did not dictate the use of still larger units, with further loss of power.

The data presented in the preceeding discussion—data amply substantiated by actual experience as well as by theoretical considerations—make it abundantly clear that any given pipe line can be protected with the maximum current economy by the use of a large number of relatively small drainage points. For coated lines, the optimum current drainage from a single point may vary from a few tenths of an ampere to three or four amperes. If more than this is drained from a single point, some of it will be wasted, and the total current demand will be increased. If the drainage per point is as high as twenty amperes, a large portion of it will be ineffective, and the current demand will be from two or three times as high as that for properly distributed drainage.

The only economical type of electrical drainage which can be applied in closely spaced small units is that which employs galvanic or "sacrificial" anodes—buried pieces of a metal which, when connected to the steel pipe, form with it a galvanic cell in which the current flow is in the direction to protect the pipe at the expense of the anode. An installation of this type

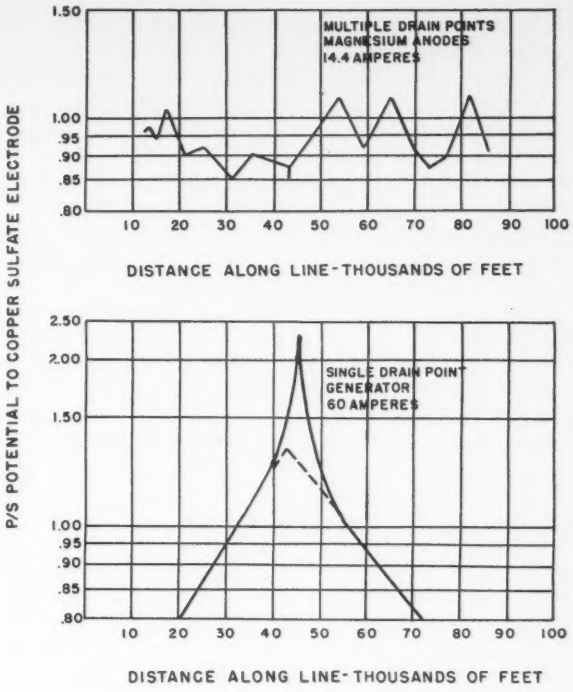

Figure 7—Field data on 13.6 mile 8″ coated line.

requires no external source of power, no additional right-of-way for structures above ground, and little or no maintenance after the original installation.

Of all the metals which have the proper electrochemical polarity with respect to steel to serve as galvanic anodes, there are only three whose cost is low enough to merit consideration; zinc, aluminum, and magnesium. Zinc, unfortunately, does not develop enough potential with respect to steel to overpower the more severe corrosive conditions, which means that only partial protection can be had at the worst locations. Aluminum has the property of polarizing rapidly in many environments; that is, a relatively non-conducting film is formed on the surface, which causes a large and rapid drop in the current output. This is a very useful property of aluminum

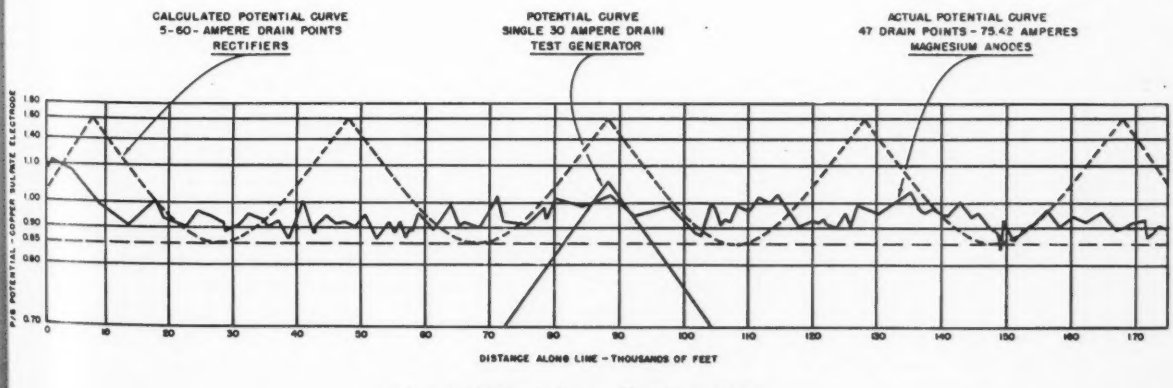

Figure 8—Field test data on 33-mile coated line.

insofar as its own resistance to corrosion is concerned, but it makes its use as a galvanic anode none too satisfactory. It is possible that a special chemical backfill can be developed which will prevent the formation of this film, and thus make aluminum available as a satisfactory galvanic anode. Even then, the available driving potential may be low enough to limit its use.

Magnesium does not present a polarization problem; furthermore, it has the highest driving potential of the three metals discussed, amounting to approximately one volt against steel in ordinary soils. Magnesium does suffer, as do the other two metals discussed, from the dissipation of some of its energy in useless "local action" when buried in most soils. Much improvement has been achieved by two means: the development of a properly formulated alloy instead of pure magnesium, and the use of a chemical backfill material immediately surrounding the anode. This material has the additional properties of attracting and holding moisture and of decreasing the resistance in the vicinity of the anode, thus permitting its use in soils of higher resistivity than would otherwise be practicable.

These developments have made it possible for magnesium, in the form of galvanic anodes, to supply current for the protection of buried structures at costs per ampere (over periods of ten years or more) which do not greatly exceed the costs per ampere from sources which are dependent on external power, even at locations where power is available. Where long power lines must be run to supply energy for rectifier units, the costs mount rapidly. The use of engine-driven generators is even more expensive, due to their high maintenance costs.

A very real saving, however, is made possible through the fact that the current derived from magnesium anodes — at costs per ampere somewhat greater than current from other sources—can be distributed in the form of many small units, thus eliminating the wasted power previously discussed, and effecting the protection of a given line with considerably fewer amperes, which swings the economic balance in favor of distributed anodes in the majority of cases studied. Furthermore, these smaller units are more flexible, and can be distributed non-uniformly along a line whose corrosive exposure is non-uniform; thus protection can be concentrated where it is most needed, and spread thin where the need is less. This effect can be seen in the uneven distribution of the anode groups shown in Figure 8.

In the actual application of magnesium anodes for the complete protection of a given line, the most economical procedure utilizes a combination of preliminary survey and engineering with a final tailoring to measure in the field. The cost of a survey with enough detailed data to permit the exact design of the system in advance might well exceed the cost of the installation itself. In the long run nothing would be gained by such a survey; the final installation would be the same. On the other hand, some information must be had in order to make an estimate sufficiently precise to be used as a basis for operations.

The quantities to be determined in planning an installation are: (1) current required per mile; (2) the size or sizes of anodes to be used; (3) size and spacing of anode groups, or of single anodes. These are dependent upon the following factors: (1) the size of the pipe; (2) the kind and condition of the coating; (3) the condition of the pipe surface, including its corrosion history; and (4) the resistivity of the soil—as a general average, and in some detail as to variations. Also pertinent are (5) the interconnections, tank farms, pumping stations, crossing lines, and other data having a bearing on interferences.

As previously mentioned, it is useless to attempt a survey in such detail as to permit a complete and precise planning of the system before installation is begun. Frequently a close approximation to the current requirements may be made solely on the basis of experience in the general locality, and available information on the kind and condition of the coating. If there is not sufficient data of this nature, a current requirement test can be run with a portable generator (welding machine) or a battery and a temporary ground bed. From the results of such a test or tests, the amount of current actually protecting a certain length of the line can be measured, and also the attenuation or decay characteristics of the line can be determined. This information permits estimation of the total current requirement per mile and determination of the spacing which will give maximum economy. If the attenuation is very flat, then the anodes may be grouped at widely spaced locations without significant increase in the total current demand. If, on the other hand, the line has very rapid attenuation characteristics, as is the case with a bare line, or a poorly coated line in low resistivity soil, the stations must be closely spaced.

The usual technique employed in determining current requirements for a rectifier-ground bed installation, that of using a generator and temporary ground bed, must be modified in order to give valid data for the design of a distributed magnesium anode system. One modification calls for the use of a small generator, or even a storage battery, so that the potential at the drainage point does not exceed 1.1 or 1.2 volts. It is somewhat difficult to obtain precise measurements under these conditions, and unless considerable time (perhaps several days) is allotted for polarization to approach equilibrium, the accuracy may be poor.

Another technique, which yields results of superior accuracy in a shorter space of time, is illustrated in Figure 9. Current is drained at the test point, practically without regard to the potential produced. Sufficient time (a few hours) is allowed to permit polarization to approach equilibrium in the vicinity of the drainage point. Then the two points on the line whose potentials are —0.85 and —0.95 are located. The current flowing past these two points toward the test drain point is then measured by means of the IR drop in a measured section of pipe, usually 100′. The difference between these two values indicates the current flowing to the line between the two points. This will be the current that would flow to this particular pipe

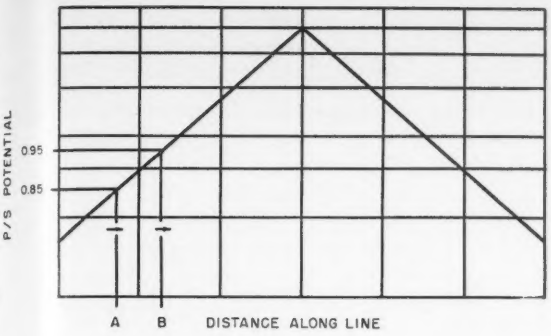

Figure 9—Current requirement test for magnesium anodes.

through its particular coating and in its particular environment, at an average potential of —0.90— which is typical of the average potential of a distributed magnesium anode installation. From the distance between the two potential points, the current requirements per mile of line may be computed. If any large variations are anticipated in soil resistivity or coating condition over the length of the line under consideration the test should be repeated for a section representative of each condition.

When the total current requirements and the tentative spacing have been determined, the soil resistivity must be considered in order to arrive at the size of anode to be employed. Magnesium anodes are available in sizes from 51 pounds down to a cored ribbon with a weight of 0.22 pounds per foot. In order to obtain a ten-year life, the 51 pound anode may be used only in soil whose resistivity is low enough to permit it to produce 0.3 ampere per anode. It is obvious that a given quantity of metal can be installed more cheaply in the form of a few large anodes than as many small ones. Consequently the largest size consistent with the available soil and the spacing requirements of the line should be used.

A preliminary selection of station sites now should be made on the pipeline maps, taking into account the foregoing considerations, in addition to those of accessibility, possible damage to crops, freedom from disturbance by cultivation, and the like. It is well at this time to plan on installing sufficient magnesium to supply the minimum current estimated for the protection of the line.

After polarization is complete on this initial installation, a survey will show quite accurately how much more is needed, in order to obtain full protection throughout the length of the line, with all the additional magnesium placed just where it is needed, and without the use of any more than is required. Thus all the information that could possibly have been obtained by a very thorough and expensive survey is available by the time it is needed, by the device of using the partial installation itself as a distributed test.

A major factor in the success of this technique is the quality of the field engineering. It is quite important that the men in charge of the actual on-the-ground installation work be the engineers responsible for the design and execution of the project. Few engineering problems are as full of unexpected variations in conditions, and subject to as many unpredictable factors, as the installation of a system of cathodic protection on a pipeline, traversing as it does soils of highly variable characteristics, and itself subject to a tremendous variation in the condition and quality of what is supposed to be uniform protective coating. It is almost impossible to design a successful installation of this type in the office, regardless of the amount of data taken in surveys, even if recourse is taken to the device of radically over-designing, so that eight or ten times the actual protection needed is prescribed. If drainage points happen to be located unfavorably, such a system may succeed in draining as little as 10% of the intended current.

Cost Analysis

Data presented previously have demonstrated the savings in power obtainable by the use of distributed drainage points of moderate size, such as can be obtained by the use of magnesium anodes. It has been stated that power can be produced with magnesium anodes, on an average, at costs which do not greatly exceed those for power from other sources. It remains to present actual economic evaluations of typical cases to demonstrate the more favorable economic position of magnesium in a preponderance of applications.

At a current output adjusted to project ten-year life the small or 17 pound anode will produce 0.1 ampere, the 34 pound anode 0.2 ampere, and the 51 pound anode 0.3 ampere. Therefore for each ampere-ten-years of current supplied there will be required ten 17 pound anodes, five 34 pound anodes, or three and one-third 51 pound anodes. At current prices, for moderate quantities the anode cost per ampere-ten years will be $50-$60, depending upon location. Direct installation costs, including labor, equipment, backfill, wire, and miscellaneous materials, but exclusive of engineering, will vary between $30 and $60 per ampere-ten years, depending upon such variables as (1) size and number of anodes that can be installed at one location, as governed chiefly by soil resistivity, (2) accessibility, (3) concentration of installation area, and (4) magnitude of the installation. This figure includes equipment amortization and overhead —in short, all direct and indirect charges.

Cost of engineering will also vary and will depend upon such factors, besides the four mentioned above, as the number of foreign line crossings and insulated laterals to be checked, and the like. Included in the cost of engineering is the preliminary test and survey, design, technical supervision of the installation, adjustment of current output of anode groups for planned life, checking for interference on or by foreign lines and rectifying when necessary, checking the efficacy of insulated joints, final survey of pipe-to-soil potentials, and the preparation of formal reports. The cost of engineering will fall in the range of $50 to $100 per ampere-ten years. This includes not

only time of the engineer, but travel expense, instrument upkeep and amortization, overhead, etc.

The initial cost for a complete installation is thus seen to be in the range $130-$220 per ampere-ten years of current actually drained. The lower figure would be found only in a large installation in open country, with soil resistivity low enough to allow the use of large anodes—in short, conditions most favorable to costs. Congested areas, higher resistivity soils, and engineering complexities, particularly when the total current demand is small, all increase the cost per ampere.

Amortization of this initial investment over the ten-year life at 7% (4½% interest, 2½% taxes), allowing for the annual decrease of one-tenth in the capital, gives a total cost per ampere-ten years ranging from $175 to $300.

The least expensive of other available sources of power is usually the rectifier—ground bed installation. Initial costs on such units range from $50 to $75 per ampere-ten years. Operating costs must include, in addition to amortization at the same rates used above, a charge of $25 to $50 for power costs; the total per ampere-ten year cost resulting is $90 to $150. The distributed anode system, then, has a cost per ampere approximately double that of the rectifier-ground bed type; but the fact that the total current demand is only one-third to one-fifth as great more than overcomes this difference.

A cost evaluation is presented in Table II of a line which was tested for rectifiers and ultimately placed under protection by the use of magnesium. The case presented is that of a 33 mile 8″ asphalt coated line through an area where soil resistivity averaged 100 to 200 ohm-cm. Attenuation data obtained from a generator and ground bed test indicated five 60-ampere rectifiers as a conservative minimum—a total of 300 amperes. The same attenuation curves together with a current measurement during test were used to estimate, by the procedure outlined above, that a maximum of 80 amperes would be required to protect the line with distributed magnesium anodes. The line was actually protected with a 10-year magnesium anode installation draining a total of 75.4 amperes. Costs for this installation are presented in the first section of Table II.

Based on furnishing the 300 amperes required of a rectifier-ground bed installation with five 60-ampere units, costs estimated on the basis of experience with comparable installations under the prevailing conditions are in the second section of Table II.

The third and fourth sections of Table II present the annual costs for the two systems of protection, amortized as described above, and including allowances for inspection and maintenance. The ratios mentioned above, and their net result, are seen in the final annual costs of $1695 and $2873 respectively.

No analysis was made of the cost of stringing power line extensions from points of power availability, although it is known that such extensions would have been required for three of the units. Even without this item, the cost of the rectifier-ground bed type of installation is nearly double that of the distributed magnesium anode installation. It may be noted that the use of rectifiers would still have been more expensive even with free power.

TABLE II

COST ANALYSIS

Actual Costs—Magnesium Anode Installation with 10 Year Life		
271 Type 5A anodes at $16.78 (Note: Some anode groups projected slightly over ten year life.)	$ 4,547	
Direct installation costs, including labor, miscellaneous material, and equipment use	3,115	
Engineering and supervision	3,232	
Total Capital Cost	$10,894	
Estimated Costs—Rectifier Groundbed Installation		
5—60 ampere rectifiers installed, including labor, materials, and equipment use, at $950	4,750	
5—Scrap iron ground beds, installed, including cables, labor, misc. materials, right-of-way, and equipment use, at $1800	9,000	
Engineering and Supervision	2,500	
Total Capital Cost	$16,250	
Annual Cost—Magnesium Anode Installation		
10-year depreciation on entire installation	$ 1,089	
Annual Survey and Inspection	225	
Interest (4½%) and Taxes (2½%) on Capital	381	
Total Annual Cost		$1,695
Cost per ampere—ten years (75.4 amps.)		225
Cost per mile for ten years		514
Annual Cost—Rectifier Groundbed Installation		
15-year depreciation on rectifier	$ 317	
10-year depreciation on ground beds	900	
Power costs at 1 cent per KWH, 15v., 50% efficiency	788	
Inspection and maintenance	300	
Interest (4½%) and taxes (2½%) on capital	568	
Total Annual Cost		2,873
Cost per ampere—ten years (300 amps)		96
Cost per mile for ten years		871

No fixed charge has been included in the annual cost statement to allow for desired profit, since an expenditure of this kind is not a direct revenue-producing investment. To determine the profit aspect, we must look for the saving to be effected. The 33 mile line discussed above was 30 months old when the first corrosion leak was discovered. Five months later three leaks were found, and in the following five months, sixteen more. It was at this point—after the occurrence of twenty leaks—that the installation described above was begun. During the month over which the work extended, there were two more leaks, and in the next two months, three more. These latter were undoubtedly due to the final penetration of pits which were already quite deep. In the six months following, **not one leak has been discovered.**

The cumulative total of corrosion leaks on this line are shown in Figure 10, plotted against the age of the line. The solid line represents the trend prior to the application of cathodic protection, and the dash line its extension, as representative of the number of leaks to be expected if no protection had been installed. It

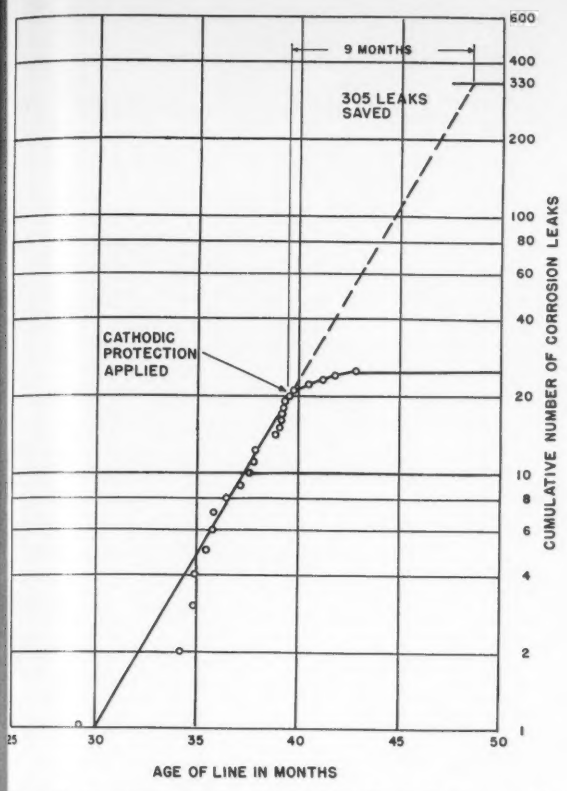

Figure 10—Cumulative corrosion leak record of 33 mile line protected by distributed magnesium anodes.

can thus be estimated that in the first nine months of protection, 330 — 25 = 305 leaks were prevented by the cathodic protection installation. At the extremely conservative figure of $300 per leak, this amounts to a return of $91,500 on the actual investment of $10,894—in nine months. Probably, in the absence of cathodic protection, the leak frequency on this line would have enforced its reconditioning or abandonment in another year or two.

Many similar comparisons of costs could be presented from an accumulation of evaluations which have been made to determine the most economical method for protection of a given pipeline system. The study presented above is typical of most of these.*

TABLE III

Average Costs for Magnesium Anode Cathodic Protection of 100 Mile Lengths of Pipe Lines Well Coated and Wrapped According to Best Modern Practice.

Pipe Line Size	Cost/100 Mi. for for 10 Yrs.	Cost/Mi. for 10 Yrs.	Cost/Mi. per Yr.	Cost/Ft. for 10 Yrs.
6″	$3,000	$30	$3.00	0.0057
8″	3,500	35	3.50	0.0060
10″	3,900	39	3.90	0.0074
12″	4,200	42	4.20	0.0080
14″	4,500	45	4.50	0.0085
16″	4,800	48	4.80	0.0091
18″	5,100	51	5.10	0.0097
20″	5,400	54	5.40	0.0102
22″	5,700	57	5.70	0.0108
24″	6,000	60	6.00	0.0114

These costs are representative of relatively poorly coated lines where current requirements for protection—by any method—are well above those for the protection of a line well coated in accordance with present practices. A guide to average total costs for the cathodic protection of new, well coated and wrapped pipelines of various sizes, in 100 mile lengths, under average conditions of soil resistivity, accessibility, and interference complexity, with a ten-year-life distributed magnesium anode installation is presented in Table III.

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1. Scott Ewing, *American Gas Association Proceedings,* 613 (1940).
2. Robert Pope, "Attenuation of Forced Drainage Effects in Long Uniform Structures," *Corrosion,* **2,** 307, 1946.
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4. E. P. Doremus, G. L. Doremus and M. E. Parker, Jr., "Attenuation Equations Applied to Cathodic Protection by Distributed Drainage," *Corrosion,* **5,** 32, 1949.

* The economics may become somewhat less favorable for galvanic anodes in soils of uniformly high resistivity, where limited anode output becomes a major factor in design.

Corrosion Resistance of Sprayed Metal Coatings*

By WALTER B. MEYER

Introduction

WITH THE PRESENT day high maintenance and replacement costs of iron and steel, oxidation of these materials presents greater problem than ever before to the corrosion engineer. The methods of combating oxidation on steel and iron are many and varied, and probably the least publicized is the metallizing process whereby pure zinc and aluminum are sprayed onto the surface to be protected.

Metallizing is continually gaining recognition in this field because of service records on jobs that have been done in this country during the past twenty years. The interior of water storage tanks metallized with zinc in the early thirties on Long Island and at Erie, Pennsylvania show clearly that the loss of weight in the steel structure can be almost completely eliminated by this method. The exterior of gas holders metallized in Southern California about the same time are in excellent condition today even though exposed to brine and industrial atmosphere. At the present moment, approximately 60,000 square feet of surface is being metallized on the wind tunnel at Moffett field, California. Due to the high humidity and salt atmosphere in this location paint coatings fail in two to three years' time.

In the production field, General Electric Company uses zinc coatings on its home freezer units; Kold-Hold Manufacturing Company metallize cold plates which are subject to continual condensation in refrigeration units and Westinghouse Electric Corporation metallizes its steel capacitor cases with zinc because of general exposure to industrial atmospheres. Many other national manufacturers use the process on similar jobs.

Other concerns have tried the process but through misapplication or improper technique have not always achieved the desired results. Whether one operates metallizing equipment of his own or has his requirements filled by an outside specialist, a rudimentary knowledge of basic principles is necessary before proper application can be made. In this regard, the structure of sprayed metal must be considered.

WALTER B. MEYER

Manager of the Metallizing Division of the John Nooter Boiler Works Co., St. Louis, Mo., formerly was with Metallizing Engineering Co., Long Island City, N. Y. He is a graduate of Illinois College, Jacksonville, Ill., and during the war instructed military personnel in metallizing techniques on the Ledo and Burma Roads and in the Mediterranean Theater.

As the wire emerges from the tip of the gun, it is rendered liquid by the surrounding jets of oxy-acetylene flame (Figure 1). As liquid the metal then can be projected by a stream of compressed air in much the same manner that other liquids are sprayed. As the small molten particles strike the large, cold mass of the part being coated, they immediately chill and freeze tight.

Figure 2 shows a single particle of sprayed metal after it has struck the surface. This particle happens to be copper which was sprayed onto hot glass in order that it might be photographed. One may visualize the type of structure that would result from hundreds of thousands of these particles building up on top of one another. The resultant stratified layers, made up of innumerable minute scales, form a coherent mass (Figure 3), with a complex structure differing vastly from the original wire. In this laminar structure, made up of thin flake-like particles lying flat and relatively parallel to each other, are found different physical properties in different directions. It is important to understand that such structures are from eight to ten times stronger parallel to the laminations than at right angles to them.

As these hot particles strike the surface of the cold base material, they are cooled rapidly from the bottom side outward. In cooling very thin oxide films are formed on the outside of each particle. The cohesion between particles is partly due to the adhesion of the molten particle to its oxide film, and to cohe-

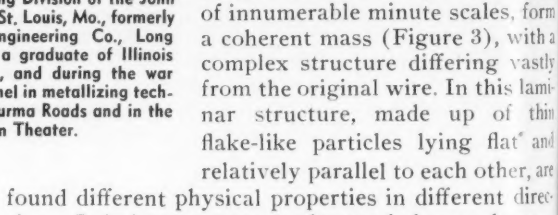

Figure 1—Wire nozzle and air cap cross-section of metallizing gu

★ A paper presented at the NACE Greater St. Louis Section meeting in St. Louis January 17, 1949.

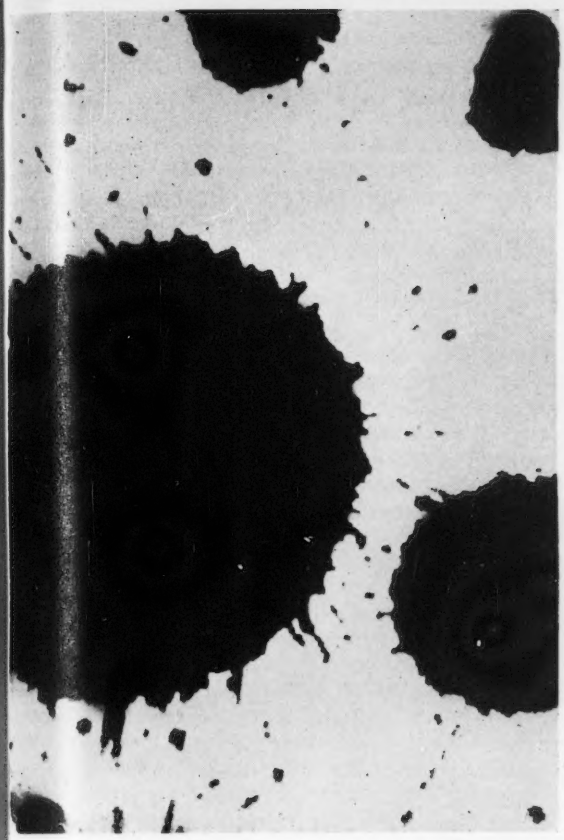

Figure 2—Single particle of sprayed metal after striking surface.

sion with the oxide envelope of the next particle. These oxides, necessarily, play an important part in the structure and strength of such coatings, and obviously affect the physical and chemical properties of sprayed metal deposits.

Tension tests of such materials essentially measure the cohesion between particles. Although these oxides are strong, they are also brittle. Therefore, it should always be remembered that all sprayed metals have low elongation and a stress-strain curve similar to cast materials.

It is obvious that such coatings should never be used to join two pieces of metal together. Metal spray may be applied only on base materials that have, in themselves, the physical characteristics necessary to meet the demands of service. It should not be used to resurface parts that are subject to heavy shock or sharp impact. Few persons question the value of sprayed coatings on journals, pump plungers or similar wearing surfaces. But results would be quite disappointing if the process were used to build up ball bearing races, flat spots on locomotive wheels, or in resurfacing gear teeth, and kindred applications.

The shrinkage of sprayed metals varies greatly with the different materials used and is unpredictable from the properties of the wire. This shrinkage results in stresses which are practically the only ones encountered in such coatings. On shafts without keyways, shrinking only causes tensile stress in the strong direction of sprayed metal, or parallel to the laminations. On flat surfaces, or on shafts with keyways, shrinking causes surface tension and stresses the coating perpendicular to the laminations, thus tending to lift the coating either by destroying the bond, or by splitting the coating next to the bond (Figure 4). These lifting forces can be counteracted by the manner in which the surface of the base material is prepared before metallizing.

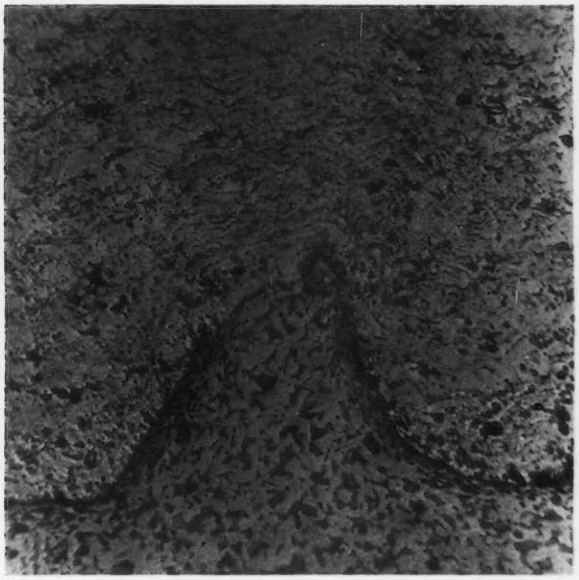

Figure 3—Cross-section of sprayed metal coating. (120x) Crystal structure is the base metal.

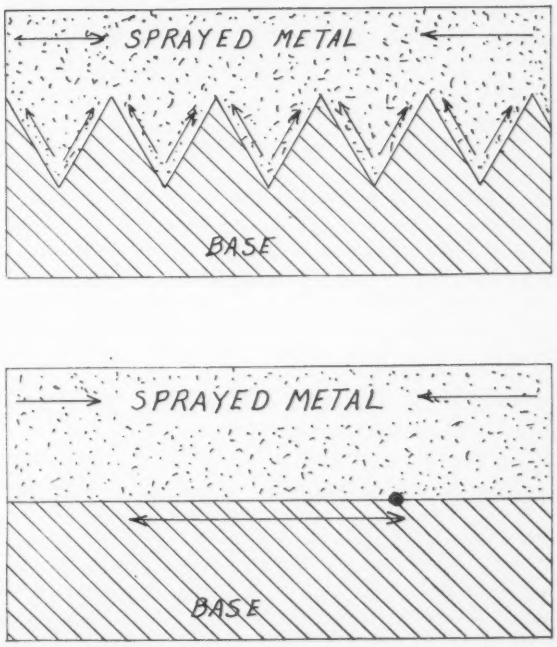

Figure 4—Shrink diagrams, with arrows indicating direction of stress. Upper: surface prepared by rough threading, thus breaking the stressed into smaller components counteracting each other. Lower: sprayed metal over flat surface.

One of the most significant properties of sprayed metal is its porosity. In some applications this porous characteristic is a definite advantage. From the corrosion standpoint, it is a distinct liability. Yet, within certain limits, the degree of porosity can be controled by the technique of the operator. In rebuilding worn machine parts the porosity, which permits retention of oil, is important. Sprayed metal bearing surfaces are consequently self-lubricating to a large degree. Retention of oil at the pressure point of bearings, even when the surface is flushed with oil, materially reduces friction and wear. In addition to its function in aiding lubrication and reducing wear, the porosity provides disposal points for the small abrasive particles resulting from initial wear.

In 1937 the metallizing shop of the author's company built up the journals of a 50 HP. armature shaft for a steel mill. Two and a half years later, the metallizer was called back to build up the journals on three more armature shafts. Why? The first job had operated continuously for more than two years. During that time, it had been fitted with one set of bearings, and just then had been cut down and fitted with undersized bearings for the first time. It was said in this case that a new shaft, operating under the same conditions, must be turned down every three months and refitted with new bearings between each turning.

It must be remembered at this point that there are certain minimum thicknesses of coatings, varying for the different metals, which may be applied. Above these, porosity of the total thickness is eliminated. A careful operator can apply coatings of uniform thickness to large flat areas by hand, but a positive check of his work is desirable. On such applications the total thickness always should be checked by means of a suitable thickness tester. Such an instrument is manufactured to measure the thickness of a non-magnetic coating applied to a magnetic base material.

In most cases a corrosion problem is an individual problem, due to the many varying factors involved. Quite often no specific information is available on the particular problem and it becomes important, therefore, that all general factors involved in solving these problems be considered and clearly understood. Only then can a decision be reached as to which metal should be used for the coating, how it should be applied, the correct thickness and proper finish. Choice of material to be used should be left to the expert in the field—the corrosion engineer—although the experienced metallizer can recommend types of metal and thickness of applications.

From the metallizer's standpoint, it is important that oxygen, acetylene and compressed air pressures be nicely balanced to secure fine atomization in order to hold porosity to a minimum. It is also important that the metallizing unit be held at the proper distance from the work so that the metal will not be chilled before it strikes the base material. Still more important, the surface must be prepared properly to receive the sprayed coating, and the coating must be applied before the prepared surface has become oxidized.

Considering the two-metal galvanic type of protection, it immediately becomes apparent that the only metals commonly used for spraying, which are anodic to iron, are zinc and aluminum. Since these metals protect iron by being themselves attacked, their porosity when sprayed is usually of little concern. All other commonly sprayed metals are cathodic to iron and protect it only when a completely non-porous coating is obtained. Here the iron is protected mechanically. For these reasons, zinc and aluminum are by far the most widely used for protecting iron and steel against corrosion by the metallizing process. Zinc coatings as thin as .004 inch are entirely practical for many types of atmospheric conditions, although heavier coatings are normally used for additional service life. Due to aluminum's tendency to oxidize, thus protecting itself from further attack, it is necessary to apply slightly heavier coatings of this material. The minimum for atmospheric corrosion is generally set at .008 inch.

Metals which are cathodic to iron are seldom used for corrosion-resistant coatings applied by the metallizing process. However, if zinc or aluminum will solve the problem, metal spraying is a solution. That's the story of the process in its application to large areas.

The protection of such items as pump plungers, agitator shafts and the lining of vessels to protect contents from contamination (where contents are neutral, or nearly so) is very much within the scope of metallizing. Particularly important is the use of the stainless alloys, the Hastelloy alloys, Monel and nickel or machine parts. Not only can the process be used for the repair of worn items made from these materials, but can also be applied to steel parts in their entirety or at points where needed.

It may be wondered what happens to such critical alloys as the stainless steels after they have passed through the oxy-acetylene flame of a spray gun. This question can be answered, in part, by citing laboratory tests.[1]

Fourteen round carbon steel bars (1⅝ inches diameter by 7 inches long) were each metallized over the middle three inches of length with 309, 310 and 420 stainless steels. Surfaces of the base metal were prepared by grooving and knurling according to the Metco method of surface preparation, with each end of the undercut portion electrically bonded with nickel electrode material. A portion of each of the metallized samples was analyzed, as was a portion of each of the wires with which the samples were sprayed. Results appear in Table I.

It will be noted that each group, except the last, contains four samples. The first three samples in each group deal with the metal sprayed deposits and the last sample shows the analysis of the wire before spraying. By comparing any of the first three with the last, the gain or loss in components is shown. (Each of the first three samples were sprayed with different types of metallizing units under varying oxygen, acetylene and compressed air pressures. Actually, the effort was to determine the effects of those varying conditions upon final coating.)

About 0.01% carbon increase during metallizing is

noticeable in the 300 series, regardless of spraying conditions. Results with type 420 are not consistent, as evidenced by samples K and M, which were sprayed under similar conditions. Samples L and P are more uniform. However, since 420 is not a true stainless steel, and is used mainly for wear resistance, the great increase in carbon content is of slight concern.

There appears a slight loss of manganese in the 300 series, but no change in the 420 type. Other results were:

Phosphorous and sulphur—no change.
Silicon—very slight loss.
Nickel—loss of about 0.20 to 1.00 in 300 series.
Chromium—loss of about 0.50 to 1.00 in all cases.
Molybdenum—no noticeable change.

Generally stated, the chemical changes during metallizing with these grades are minor and sufficiently slight to be considered negligible for most applications.

Figure 5 shows the microstructure of a typical section of metallized coating. This structure differs considerably from what is found in either cast or rolled steel. As one might expect, the metal is in irregular layers of microscopic thickness with a thin film of oxide between each. Sprayed deposits in the tests were about as resistant to the etching re-agents as the original wire.

Specimens of each grade were heated to 1950° F. for six consecutive 15-minute intervals, i.e., held at 1950 degrees for 15 minutes, air cooled to room temperature, then reheated, etc. The base metal scaled badly; the areas metallized with 420 scaled an appreciable amount. However, the 309, the 310 and the 311 samples showed almost no scale whatsoever and were merely discolored by the heat. Contrary to expectations, the latter samples remained intact during these heatings in spite of the fact that the coefficient of expansion of this type of material is approximately twice that of carbon steel.

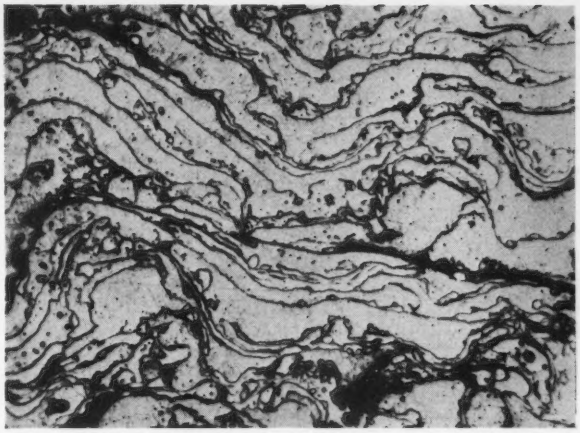

Figure 5—Microstructure of typical section of metallized coating. (500x) Transverse. Unetched.

To give a complete picture of metallizing, methods for preparing surfaces must be mentioned, although to go into detail would be a story in itself. There are generally five basic processes, and each has its place, depending on the ultimate service to which the piece will be put. Worth noting is the fact that it is possible to secure bond strengths of 4,500 pounds per square inch in tension and 15,000 pounds per square inch in shear between the sprayed deposit and base material. Interesting, too, are the results of several pull samples tested recently. Standard 1⅛-inch diameter test bars were machined from regular bar stock, and the center portion cut down to ¾-inch diameter. On one end standard threads were cut into the solid metal. The opposite end was undercut to a size .020 inch below the root of the thread. Five of these surfaces were threaded and flash coated with molybdenum, while two were machined smooth and coated similarly. Five samples were built up by metallizing with 0.10 carbon steel and two were built

TABLE I

Chemical Analysis Performed on Metal Sprayed Samples*

October 15, 1948 Metallurgical Report 4-659-48

Code	Grade	C	Mn	P	S	Si	Ni	Cr	Mo	Co	Cu	N
A.....	309	.092	1.53	.017	.014	.32	13.66	22.54	.04	.08	.06	.044
B.....	309	.091	1.51	.017	.016	.32	13.50	22.64	.04	.07	.06	.046
C.....	309	.094	1.64	.017	.017	.34	13.70	23.00	.05	.07	.06	.048
AW....	309	.082	1.70	.021	.018	.35	13.90	23.26	.05	.08	.06	.043
D.....	310	.23	1.49	.025	.014	.94	20.86	23.66	.17	.04	.08	.047
E.....	310	.23	1.44	.023	.016	.93	20.80	23.56	.14	.04	.08	.049
F.....	310	.23	1.61	.025	.015	.99	20.82	24.18	.17	.04	.08	.048
DW...	310	.22	1.65	.027	.016	1.03	21.30	24.56	.12	.08	.09	.046
G.....	311	.075	1.57	.016	.014	2.19	24.74	18.96	.01	.06	.17	.042
H.....	311	.078	1.56	.015	.014	2.22	25.14	19.10	.01	.06	.18	.045
J.....	311	.075	1.63	.014	.013	2.25	25.26	19.34	.01	.06	.19	.047
GW....	311	.065	1.71	.015	.013	2.34	25.76	19.56	.01	.07	.19	.041
K.....	METCO No. 420	.34	.35	.022	.022	.38	.43	12.18	.04	None	.17	.055
L.....	METCO No. 420	.39	.36	.022	.022	.37	.44	12.19	.04	None	.17	.080
M.....	METCO No. 420	.46	.40	.022	.023	.38	.44	12.33	.04	None	.17	.080
KW...	METCO No. 420	.34	.39	.023	.023	.44	.47	12.84	.02	.01	.19	.057
N.....	Crucible No. 420	.49	.34	.019	.015	.28	.22	12.90	.04	None	.10	.070
P.....	Crucible No. 420	.47	.33	.019	.015	.28	.22	13.01	.04	None	.09	.092
NW...	Crucible No. 420	.39	.35	.020	.012	.29	.23	13.68	.05	.01	.09	.061

* By the Crucible Steel Company.

Figure 6—Metallized samples after pull tests.

TABLE II
Results of Pull Samples

Sample No.	Metal Sprayed	Method of Preparation	Failure Occurred
1	Steel .10% C.	Molybdenum Bond over smooth surface	23,900 lbs.
2	Steel .10% C.	Electric Bond	32,500 lbs.
3	Steel .10% C.	Rough Thread and Molybdenum Bond	25,600 lbs.
4	Steel .10% C.	Rough Thread and Electric Bond	43,200 lbs.
5	Steel .10% C.	Molybdenum Bond over smooth surface	32,000 lbs.
6	Steel .25% C.	Rough Thread and Molybdenum Bond	48,000 lbs.
7	Steel .25% C.	Rough Thread and Molybdenum Bond	45,000 lbs.

Tests conducted in laboratories of the John Nooter Boiler Works Company.

up with 0.25 carbon steel. Threads were then cut into these metallized sections.

The samples were subsequently pulled in a tensile testing machine. The load at which they failed is indicated in Table II, and results may be viewed in Figure. 6. It is significant that only in the two cases where samples were turned smooth before applying the molybdenum did the failure take place at the bond. In all other instances, the sprayed metal sheared at the root of the thread, leaving the bond intact.

Another field for metal spraying lies in its application to resist heat corrosion. There are three variations used for coating parts subject to furnace temperatures and oxidizing gases in the heat treating and metal melting industries.

The first variation, known as Process 11, is an inexpensive yet satisfactory method of protecting steel surfaces from the corrosive effects of hot gases. The surface to be protected is first grit blasted and then metallized with .006 inch of aluminum. A special bitumastic sealing compound is applied directly over the aluminum. The article is then heat treated at 1450° F. to cause penetration of the aluminum into the iron or steel surface. The sealing coat protects the aluminum from oxidizing, and gives it time to absorb into the iron or steel. Final coating consists of an external surface of aluminum oxide, and under this a coating of aluminum in solid solution of iron. Near the surface the concentration of aluminum is relatively high. This process protects satisfactorily up to 1600° F. and will withstand the action of sulphur gases.

Process 33 is used to protect iron and steel against the action of corrosive gases where temperatures range from 1600 to 1800° F., and where gases do not contain large amounts of sulphur. Again the surface is grit blasted and sprayed with .010 inch thickness of chromium-nickel alloy. The surface is then painted with a bitumastic sealer and placed directly in service without heat treatment. This sealer contains metallic aluminum. The spongelike surface of sprayed chromium - nickel alloy presents an absorbent base into which the aluminum penetrates as it melts. Since aluminum has a great affinity for alloying with chromium, nickel and iron, it penetrates through the sprayed coating and alloys with the base material, forming an actual alloy bond consisting of an alloy composed of chromium, nickel, aluminum and iron.

Process 45 provides maximum protection against heat oxidation, withstanding even strong sulphur gases. The surface is grit blasted and then sprayed with a 0.015 inch thickness of chromium-nickel alloy. Pure aluminum 0.004 inch thick is applied over this and that surface is finally painted with the bitumastic sealer containing metallic aluminum. No heat treatment is required in this application. As in the case of Process 33, the aluminum rapidly penetrates into the porous structure of the chrome-nickel coating, forming an alloy bond with the base metal. This alloy consists of chromium, nickel, aluminum and iron.

Industry began tinkering with metallizing back in

1921. At that time, the few concerns that experimented with the process in this country used European equipment. The first American metallizing equipment was produced in 1932 and has been developed and improved ever since.

British industry began experimenting with the process about the same time. It might be added that the process there is highly honored by industry. In England, 96 per cent of all metallizing is in the field of corrosion resistance. Over there the various engineers, consultants and educators, who have so thoroughly become convinced of the effectiveness of metallizing, recommend it unhesitatingly.

Among them are W. S. Atkins & Partners, the consulting engineers who specified metallizing on the Abbey Works, Steel Company of Wales—the largest metallizing job ever specified. Specifications called for the spraying of aluminum .004 inch thick on all structural work above the crane rails in all buildings of this steel mill. This amounted to coating 45,000 long tons of steel, involving the spraying of millions of square feet in a job lasting three years. Another English firm, Rendel, Palmer & Tritton, was responsible for the specification of metallizing on the Howrah bridge over the Hoogley River at Calcutta, India. Held up during the war, this job is now proceeding again. The bridge is much larger and more pretentious than any now existing or contemplated over the Mississippi River. The lock gates in the Namur River in Belgium were sprayed with zinc in 1926 and are still giving perfect service. A bridge over the same river received the same application in 1928, with similarly good results.

However, metallizers in this country are not mere babes in the woods. Such projects as the zinc spraying of tuna clippers on the Pacific Coast — hulls, bulkheads, fish tanks and superstructures can be pointed to. Deck beams of the Missouri Pacific's bridge over the Kaw River at Kansas City, Mo., were sprayed in 1936. Because refrigerator and cattle cars waited on the bridge to get into the adjoining switching yard, drippings were deteriorating steel work below the rails. The job is withstanding the tests of time.

The author's company has the distinction of having performed what is perhaps the largest aluminum spray job ever contracted in this country. The exterior of all aluminum alloy structurals that went into 72 railroad cars for Missouri Pacific's Sunshine Eagles were coated. These copper-bearing aluminum members are in service in the alkali-laden soil of the Southwest. There is just enough difference in potential between the alloy and pure aluminum to afford the necessary amount of protection.

The manner in which these jobs were done and the results shown give a faint glimmer of what the metallizer can do, and will be doing more of, in spray coating structurals for bridges, industrial buildings and the other man-made giants of metal where the corrosive element must be taken into consideration.

Conclusion

Since the corrosion engineer is vitally interested in long-life and low cost maintenance of structural steel, the metallizing process should be considered on all jobs subject to accelerated atmospheric corrosion such as that encountered in industrial areas and on the sea coast. While the initial cost of the application of zinc or aluminum to such structures is higher than with other methods, the yearly cost will be considerably reduced. Steel plates and members, which have oxidized and corroded away to the point where structural strength has reached the minimum safety factor, may be metallized in place and the service life of the parts increased many many times. In original design lighter sections can be used where the zinc or aluminum is applied to prevent corrosion for periods of twenty to thirty years or more. With competent contract shops located from coast to coast, more and more companies are taking advantage of this process.

References

1. "The Corrosion Resistance of Metal Sprayed Stainless Steels," by Crucible Steel Company, Report before the American Metallizing Contractors' Association, October 15, 1948.

DISCUSSIONS ARE INVITED

Readers who wish to submit written information additive to articles published in CORROSION, or who wish to register differences of opinion with respect to any articles are urged to send such discussions to Dr. F. N. Alquist, Chairman, NACE Editorial Review Committee, Organic Research Laboratories, 20A Building, Dow Chemical Co., Midland, Mich. Doctor Alquist will submit such discussions to a member of the review committee, and after review and approval the discussion will be published.

The expression of opinions about or the addition of information to that contained in technical articles will advance the interests of NACE and make CORROSION more valuable to the membership.

An Investigation of Structural Steel Shop Coat Priming Paint*

By S. C. FRYE*

Introduction

THE PROBLEM of preventing structural steel from rusting in the interval between shop priming and field painting, that is while the steel is being shipped, stored, or erected, is of prime importance. If the primer fails and the steel rusts during one of these periods, as it frequently does, costly field cleaning and repriming are necessary. Obviously, this problem is of vital interest to steel fabricators and paint manufacturers alike, and is one to which both industries have devoted considerable attention. The ultimate owner of the steel is also very much involved in the protection afforded by the shop and field coats because his maintenance and repainting costs will depend on the life of the undercoats applied.

Recognizing the problem as a common one, Bethlehem Steel Company, in cooperation with The National Lead Company, undertook an investigation which involved the formulation and performance evaluation of a group of shop-coat paint primers. Recognizing also, the interest of the consumer in the results that would be obtained, Jonathan Jones, Chief Engineer, Fabricated Steel Construction, of Bethlehem Steel Company, invited John L. Beckel, Assistant Engineer of Structures, New York Central System, and Morris Goodkind, Bridge Engineer, New Jersey State Highway Department, as representative railway and highway bridge engineers respectively, to participate in the work and report the findings to the bridge engineering profession. A committee, formed to determine and evaluate the exposure results, included the above and also personnel from the National Lead Company's Research Laboratories and the Research Department of Bethlehem Steel Company.

General specifications set up as a guide in formulating primers for the test were:

1) The primer should retard the rusting of structural steel for at least one year, or until the structure can be erected or field coated. No more than spot-priming should be necessary at the end of this period.
2) The primer should require only the standard wire brush cleaning prior to painting, rather than expensive cleaning methods, such as sand blasting or flame cleaning.
3) The primer should be quick-drying, so that the steel can be handled within 8 hours after painting without damage to the paint film.
4) The primer should have an open formula so that it can be supplied by a number of reliable manufacturers.
5) It should have good application properties, so that it can be applied easily and correctly by either spray or brush application.

For testing the primers, four surface conditions encountered in fabricating shops were chosen. Hot-rolled steel with mill scale reasonably intact as received directly from the rolling mills was designated as surface "A." Less than 10% of the surface was rusted. Surface "B" was hot-rolled steel allowed to weather until 30-50% of the surface had rusted, with consequent removal of some of the mill scale. Hot-rolled steel allowed to weather until 60-80% of the surface had rusted, with consequent removal of most of the mill scale was designated as surface "C." Hot-rolled steel pickled in inhibited acid to remove all of the mill scale and provide a clean rust-free surface for painting was designated as surface "D."

Surfaces "B" and "C" are most frequently encountered in fabricating shops, and are most difficult to protect by painting, in that the surface contaminants resulting from weathering adversely affect paint performance.

Test Procedure

The panels chosen for the test were one foot lengths of 4" x 4" x ⅜" structural steel angles. These were selected because from previous experience, it was known that the scale on the angles was typical of mill scale found on structural steel. Edge effects such as those encountered in practice were also represented; in addition, this size angle made handling easier during the course of the test.

The effect on primer paint life of pre-treatment by a wetting agent compatible with subsequent primers was also determined. Several series of test panels were prepared by treating the angle surfaces with a thin film of raw linseed oil, or modifications of linseed oil, prior to the application of the paint. Raw linseed oil and several modifications of linseed oil were used as the pre-treatment agents because of the established ability of linseed oil to thoroughly wet and penetrate the surface of rusted steel.

Seventeen paints using three types of pigmentation were formulated for the test.

★ A paper presented at the Fifth Annual Conference, National Association of Corrosion Engineers, Cincinnati, Ohio, April 11-14, 1949.

* Research Department, Bethlehem Steel Company.

The pigmentations used were the following:

1. 100% of 97% Grade Red Lead.
2. 75% of 97% Grade Red Lead and 25% of Iron oxide (85% Fe_2O_3).
3. 60% of 97% Grade Red Lead, 20% of Iron oxide (85% Fe_2O_3), 15% of Magnesium Silicate, and 5% of Mica.

The vehicles used were the following:

1. Raw linseed oil.
2. Alkyd Resin Solution—25% phthalic anhydride linseed oil type—70% solids.
3. Alkyd Resin Solution—34% phthalic anhydride linseed oil type—50% solids.
4. Alkyd Resin Solution—30% phthalic anhydride linseed oil type—50% solids.
5. Alkyd Resin Solution—34% phthalic anhydride linseed oil type—50% solids, raw linseed oil added.
6. Alkyd Resin Solution—27% phthalic anhydride castor oil type—80% solids.
7. 33 Gallon Phenolic Varnish—composed of 100% para phenyl phenol formaldehyde resin — 60% chinawood oil—40% linseed oil—60% solids.
8. Oil combination—20% chinawood oil—80% boiled linseed oil.

The paints were applied by spray, this being the method generally used in fabricating shops, although they could have been brushed. Panels of surfaces "A," "B," and "C" were hand wire brushed and solvent washed. As previously mentioned, panels of surface "D" were pickled and dried just prior to painting.

The paints were applied by what were called normal and controlled film thicknesses. Normal film thicknesses may be defined as the film thickness of paint which an experienced operator would think necessary to properly coat the panel. Controlled film thickness involves the application of a pre-calculated amount of paint to obtain a uniform dried film thickness of 2.0 mils ± 10%. Due to the variable nature of the surfaces it was decided to make each type of test in quadruplicate, except for the pickled angles "D." Since the pickling process eliminated surface variations, it was felt that, in this case, duplicate tests would be sufficient. Including all surface conditions each paint required 56 angles. There were some exceptions to this practice due to certain eliminations and modifications.

The panels were exposed at 45° facing south, at Perth Amboy, N. J., an industrial marine site, and at New Kensington, Pa., an inland semi-industrial site.

Inspection of Panels

Prior to the initial panel inspection, members of the inspection committee agreed on certain standards for determining the performance or protective value of the paints during the course of exposure.

A rating of 8 was given to those panels on which the conditions of the primer surface were such that no touch-up work would be required prior to subsequent painting. This rating approximates ASTM D-610-43 Type 2 No. 8.

A rating of 7 was given to those panels on which the condition of the primer surface would require no more than 20% spot primer prior to subsequent painting. This rating approximates ASTM D-610-43 Type 2 No. 7.

A rating of 6 was given to those panels on which the condition of the primer surface had failed just sufficiently to require complete repriming prior to subsequent painting. This rating approximates ASTM D-610-43 Type 2 No. 6.

In addition, and in order to differentiate further between panels that had a rating of 8, and those that were in better condition, a rating of 8+ was given to panels that would have an ASTM rating of 9 or 10. Test ratings of 5, 4, and 3, corresponding to ASTM ratings of 5, 4, and 3, were also included to bring out further differences and excessive failures among the primers that required complete repriming.

The panels were inspected by the inspection committee at both test sites after 9, 13 and 19 months of exposure.

Summary of Findings

The findings presented are based on the correlation of inspection data and a statistical analysis of these data taken after 9, 13 and 19 months exposure.

Significant failure of various primers had occurred after 13 months, particularly on the corroded or rusted surfaces "B" and "C." These surfaces were either typical of, or slightly poorer than the majority of structural steel surfaces to which primer paints are applied. The freshly rolled surface, "A," and the pickled surface, "D," showed very little failure. It should be remembered that, in general, it is not possible to obtain surface conditions comparable to "A," and furthermore, in general, it is impracticable to pickle structures, or clean by sand blasting just before painting, the condition represented by surface "D." Thus conclusions based on the life of primers applied to surfaces "B" and "C" are of the most practical value.

After 19 months exposure, 100% red lead in linseed oil was the primer which afforded the best protection, based on the average ratings for a controlled film thickness of 2 mils and also for the normal method of applications. The 100% red lead in linseed oil primer did not, however, meet requirement 3 of the specification set up, that is, it took longer than 8 hours to dry. The average film thicknesses of the red lead in linseed oil paint, on the panels where the paint was applied at the normal thickness, were considerably greater than for the other paints applied at normal thicknesses.

Of the primers that met the 8-hour dry-to-handle requirement, the following two afforded the best protection on "B" and "C" surfaces throughout the test:

1) A pigment combination of 60% red lead, 20% iron oxide, 14% magnesium silicate, 6% mica—in 34% phthalic anhydride linseed oil glyceryl phthalate resin.
2) 100% red lead—in 30% phthalic anhydride linseed oil glyceryl phthalate resin thinned with 2%, by volume, of a 1:1 mixture of V. M. & P. naphtha and kerosene.

A primer composed of 100% red lead and a 27% phthalic anhydride glyceryl phthalate dehydrated castor oil resin gave surprisingly good results on a very limited test. (4 panels compared to 16 for the other tests.)

Because of the limited tests that were made, the author is hesitant about drawing comparisons with the other primers. Further investigations of dehydrated castor oil primers should be made first.

Pre-treatment

Pre-treatment of the rusted metal surface had a decided beneficial effect on the life of the primer. Three types of pre-treatment oils were used.

Raw Linseed oil. Complex A, a maleic anhydride treated linseed oil. Complex B, also a maleic anhydride treated linseed oil but containing a higher percentage of maleic anhydride.

Raw linseed oil performed the best based on a number of tests. Complex A, on the basis of one test was as good as raw linseed oil. Complex B was not as good as raw linseed oil. The tests indicated that after pre-treating the surfaces with linseed oil, all the various primer paints tested (including one with a 100% alkyd vehicle) performed practically as well as red lead in linseed oil on un-pretreated surfaces. Figure 1 is a graph of exposure ratings versus months of exposure showing the beneficial effect of pre-treatment and the thinner adjustment mentioned previously (i.e., the addition of 2% of a 1:1 mixture of V. M. & P. naphtha and kerosene) on the primer. The primer used in this particular test is the 100% red lead in a 30% phthalic anhydride linseed oil alkyd. The heavy line drawn in Fig. 1 at the exposure rating of 6 serves as an indication of the point

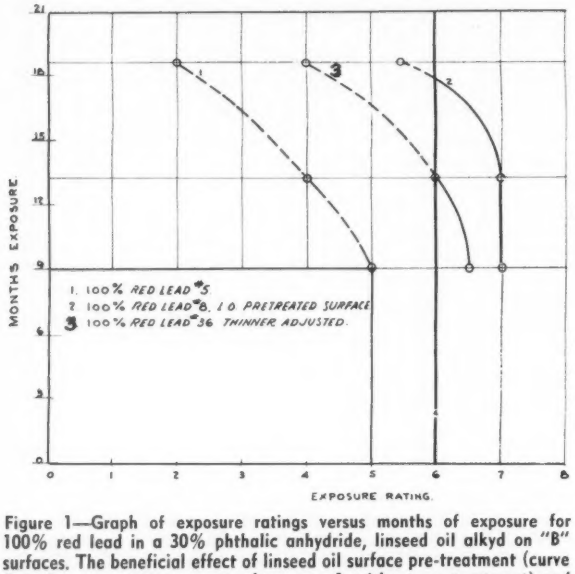

Figure 1—Graph of exposure ratings versus months of exposure for 100% red lead in a 30% phthalic anhydride, linseed oil alkyd on "B" surfaces. The beneficial effect of linseed oil surface pre-treatment (curve 2, with pre-treatment, compared to curve 1, without pre-treatment) and also the beneficial effect of higher boiling thinners, such as V. M. & P. naphtha and kerosene (curve 3), are shown.

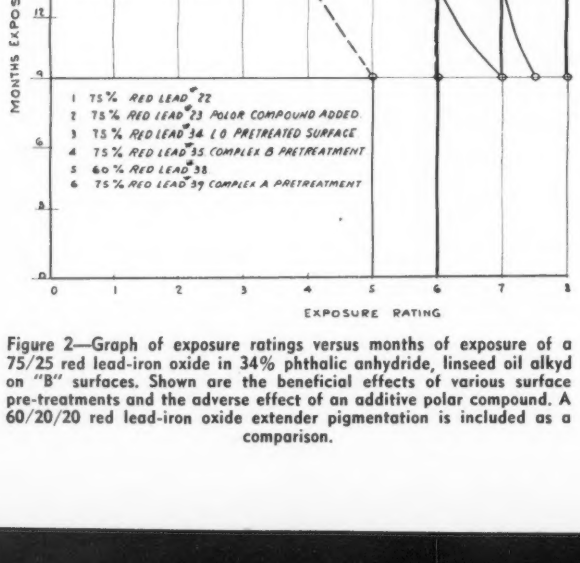
MONTHS EXPOSURE
EXPOSURE RATING
1. 75% RED LEAD #22
2. 75% RED LEAD #23 POLAR COMPOUND ADDED
3. 75% RED LEAD #34 L.O. PRETREATED SURFACE
4. 75% RED LEAD #35 COMPLEX B PRETREATMENT
5. 60% RED LEAD #38
6. 75% RED LEAD #39 COMPLEX A PRETREATMENT

Figure 2—Graph of exposure ratings versus months of exposure of a 75/25 red lead-iron oxide in 34% phthalic anhydride, linseed oil alkyd on "B" surfaces. Shown are the beneficial effects of various surface pre-treatments and the adverse effect of an additive polar compound. A 60/20/20 red lead-iron oxide extender pigmentation is included as a comparison.

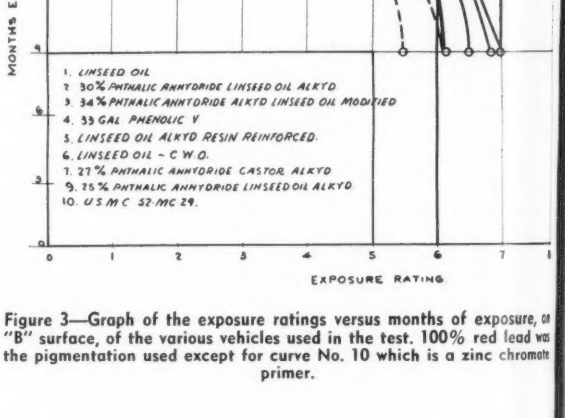
MONTHS EXPOSURE
EXPOSURE RATING
1. LINSEED OIL
2. 30% PHTHALIC ANHYDRIDE LINSEED OIL ALKYD
3. 34% PHTHALIC ANHYDRIDE ALKYD LINSEED OIL MODIFIED
4. 33 GAL PHENOLIC V
5. LINSEED OIL ALKYD RESIN REINFORCED.
6. LINSEED OIL - C.W.O.
7. 27% PHTHALIC ANHYDRIDE CASTOR ALKYD
9. 75% PHTHALIC ANHYDRIDE LINSEED OIL ALKYD
10. U.S.M.C. 52-MC 29.

Figure 3—Graph of the exposure ratings versus months of exposure, on "B" surface, of the various vehicles used in the test. 100% red lead was the pigmentation used except for curve No. 10 which is a zinc chromate primer.

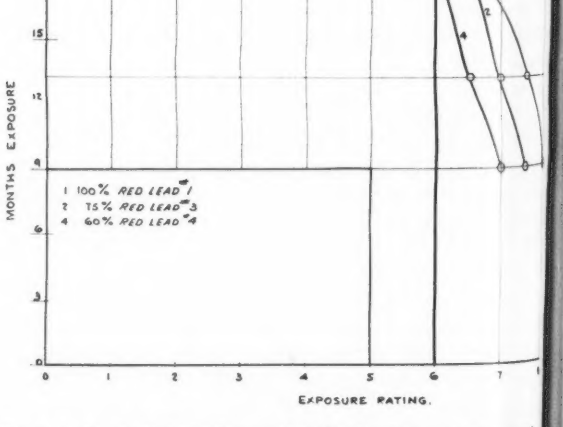

Figure 4—Graph of the performance of the three types of pigmentation tested, in linseed oil, on "B" surface.

at which complete repriming is necessary. Portions of the curves (solid lines) to the right of this line are at ratings where no touch-up or only 20% touch-up is necessary before repainting. The portions of the curves (dotted lines) to the left of the heavy line indicate that failure has progressed beyond the point at which complete repriming is necessary. Thus from Figure 1 the primer on the un-pretreated surface (Curve 1) had failed beyond the point of complete repriming even at 9 months, while the same primer on a linseed oil pre-treated surface (Curve 2) gave good protection well past the 13 month inspection and almost to the 19 month inspection.

Figure 2 shows the beneficial effects of the types of pre-treatments on a 75% red lead, 25% iron oxide in a 34% phthalic anhydride linseed oil alkyd. It should be noted that ratings of paints on pre-treated surfaces (Curves 3, 4, and 6) all lie to the right of the heavy line while the same paint (Curve 1) on the un-pretreated surface lies wholly to the left on the heavy line. The adverse affect of the addition of a polar compound (Curve 2) (2 amino, 2 methyl, 1 propanol) to the paint is also shown.

Vehicles

A study of the influence of vehicles on weathering, regardless of pigmentation was made. A summation of this study is shown in Figure 3. On "B" and "C" surfaces, raw linseed oil and 34% phthalic anhydride glyceryl phthalate linseed oil vehicles (Curves 1 and 3 of Figure 3) were the best overall vehicles, but the latter met the drying time specification, while raw linseed oil did not.

The 27% phthalic anhydride dehydrated castor oil resin (Curve 7, Figure 3) was also very good, but as mentioned previously, the data are based on limited tests, that is, on only 4 panels compared to 16 from the other tests.

Curve 10 of Figure 3 is the exposure rating of U.S.M.C. 52-MC-29 primer paint, which is zinc chromate, zinc oxide, titanium dioxide, and extender in a linseed oil modified alkyd.

Pigments

A study was also made in which various pigments were tested with the same vehicle. Figure 4 is a graph of the performance of the three pigmentations used in the test with linseed oil vehicle. These curves are all to the right of exposure rating 6, indicating good performance. However, these primers had the disadvantage of having prolonged drying times and did not meet the requirements of the test.

Figure 5 shows the performance of different pigmentations in various vehicles. Here it can be seen that except for the dehydrated castor oil vehicle

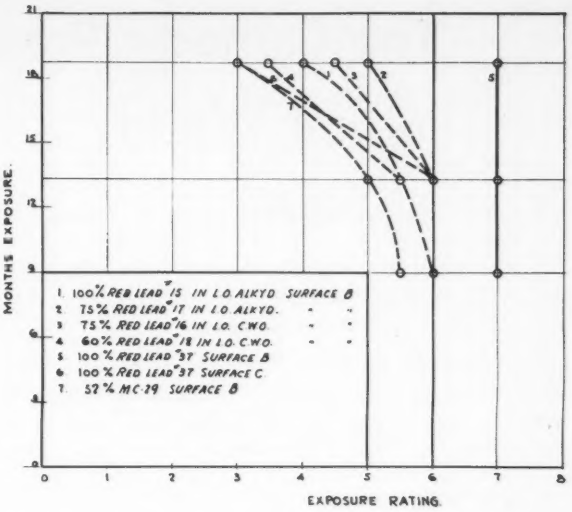
MONTHS EXPOSURE
EXPOSURE RATING
1. 100% RED LEAD "IS" IN L.O. ALKYD SURFACE B
2. 75% RED LEAD "IT" IN L.O. ALKYD. " "
3. 75% RED LEAD "16 IN L.O. C.W.O. " "
4. 60% RED LEAD "18 IN L.O. C.W.O. " "
5. 100% RED LEAD "37 SURFACE B
6. 100% RED LEAD "37 SURFACE C
7. 52% MC-29 SURFACE B

Figure 5—Graph of the ratings of various pigments in various vehicles.

(Curve 5) all of the curves are on the failure side of exposure rating 6. An analysis of the data shown in Figure 5 indicates that no one pigment combination was outstanding in its performance, that is, no one pigment was materially better than the others. Evidently all of the combinations contained sufficient corrosion inhibiting pigments to give good protection.

Plans for Further Testing

In view of the results obtained, it is planned to continue and enlarge the program to cover a wider field of primers. Further work will be done on pretreatments with the limitation of the eight-hour dry-to-handle objective kept in mind.

The Author's Company has had considerable success with a 75/25 red lead/iron oxide pigment combination as a shop coat. Experience with this combination has led to the formulation of a tentative specification for a primer of this type with either a glyceryl phthalate linseed oil modified resin, or a phenolic resin chinawood oil-linseed oil varnish, as the vehicle. Results with primers such as these have been good, both in test and field work.

Primers of this specification were not included in the test, as at the time this work was initiated, the ideas on primers were not clearly defined. In the continuation of this investigation, primers conforming to the author's specifications will be included. Further constructive data should be available for presentation at the conclusion of the second series of tests.

The Cathodic Protection of Steel Piling In Sea Water*

By H. A. HUMBLE*

Introduction

THE WORK REPORTED in this paper is part of a general program of research designed to evaluate the various factors involved in the use of magnesium anodes for the cathodic protection of steel in sea water. Previous work[1] has shown that certain magnesium alloys are satisfactory sacrificial anodes for sea water, service being characterized by high solution potentials, comparative freedom from polarization effects, and by low metal consumption per ampere hour of current realized. It was shown that virtually complete protection can be achieved at current densities of from 3-6 MA/Sq. Ft., depending upon the method of application. This prior work exclusively dealt with a continuously immersed cathode which was subject to relatively uniform corrosion attack.

The present work deals with the application of cathodic protection to steel structures, such as marine piling, where varying conditions of exposure and non-uniform corrosion attack are encountered. The corrosion profile of such a piling after five years exposure at Kure Beach, N. C. is shown qualitatively in Figure 1. It should be noted that the intensity of corrosion attack varies not only from zone to zone, depending upon the type of exposure, but that there is also considerable variation within these individual zones.

It is obvious that zones 1 & 2, where the corrosion attack is most severe, cannot be protected cathodically. Here protection may be provided through the use of protective coatings, such as paint, concrete, or corrosion resistant metals. The major objectives of this work were to determine the effectiveness of cathodic protection in the remaining three zones, to determine how such protection can be applied most economically, and to learn something of the mechanism of the corrosion attack which produces the profile shown in Figure 1.

Experimental Techniques

In these investigations the three types of experimental exposures shown in Figure 2 were employed. These consisted of channel iron racks on which were mounted the corrosion test plates, the plates being insulated from the supporting racks by bakelite washers and sleeves. The racks were suspended in a vertical position in the intake basin of The Corrosion Testing Station at Kure Beach, N. C. at such an elevation that all plates below No. 3 were continuously submerged at mean low tide (M.L.T.), while plates Nos. 1, 2, and 3 were alternately exposed to the atmosphere and immersed in seawater as the result of tidal changes. Nos. 1, 2, and 3 were at least

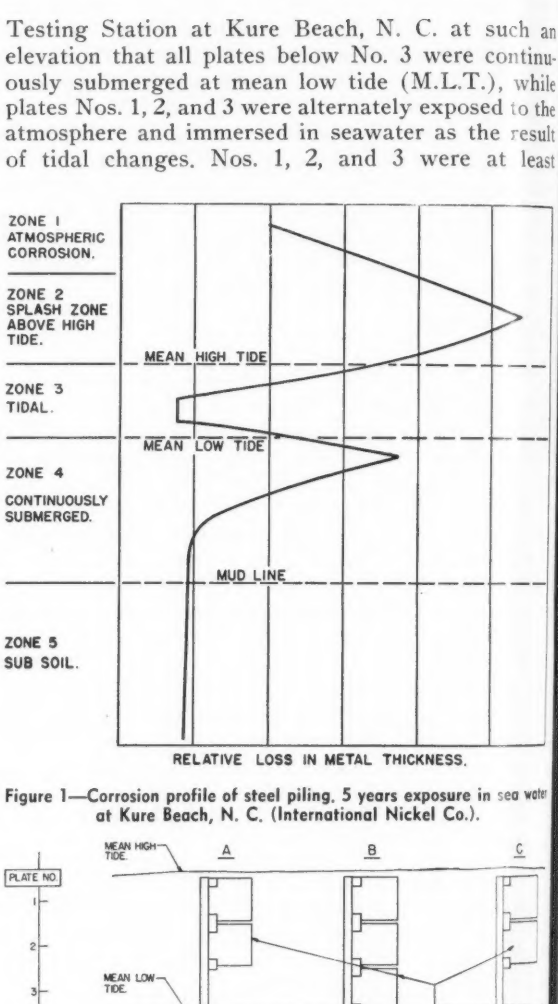

Figure 1—Corrosion profile of steel piling, 5 years exposure in sea water at Kure Beach, N. C. (International Nickel Co.).

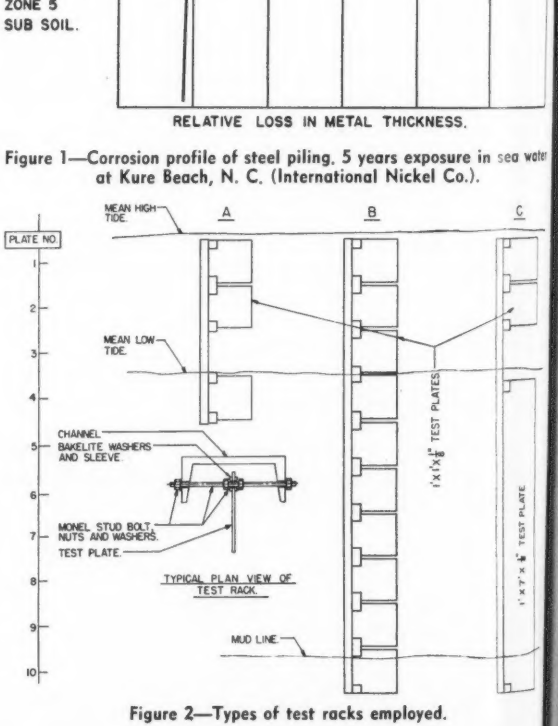

Figure 2—Types of test racks employed.

★ A paper presented at the Fifth Annual Conference, National Association of Corrosion Engineers, Cincinnati, Ohio, April 11-14, 1949.

* Metals Protection Laboratory, The Dow Chemical Company.

partially immersed for an estimated 25%, 45%, and 70% of the time respectively.

Corrosion Test Specimens

The test plates were usually 1′ x 1′ x ⅛″ in size, although on some racks a single continuously immersed plate 1′ x 7′ x ⅛″ was employed (Figure 2-C). While these latter racks had the obvious disadvantage of supplying no information on the distribution of current below M.L.T., they were considerably easier to assemble.

The analysis of the steel specimens used in these experiments is shown in Table I. It was suggested that the results observed for mild steel (composition A) might in part be due to its low copper content and relatively high sulfur. In order to determine the effect of composition a series of plates having composition B were exposed. These latter plates will here-after be designated as "low alloy" steel. A metallographical examination of these materials showed them both to be clean "killed steel."

TABLE I

	Composition A	Composition B
Percent Manganese	0.34	0.35
Percent Copper	0.027	0.11
Percent Nickel	0.01	0.68
Percent Sulphur	0.068	0.05
Percent Carbon	0.22	0.07
Percent Phosphorus	0.08	0.02

In addition to the above steel compositions, two racks were installed on which Monel plates were exposed in the upper three positions.

Surface Condition

A variety of surface conditions were employed in these tests; these include the following:

1) Sandblasted
2) Sandblasted, calcareous coated
3) Sandblasted, painted
4) Mill scale
5) Mill scale, calcareous coated

The calcareous coatings were precipitated by the application of a current equivalent to 50 MA/Sq. Ft. for a five day period just prior to starting the tests. The painted plates were given one coat of a cold bituminous coating* which was applied over a sandblasted surface.

Cleaning Procedure

The test plates were weighed to the nearest 0.5 gram prior to exposure. At the completion of the test the plates were cleaned by sandblasting using low pressure air and a worn nozzle, and their loss in weight determined. It has been shown that such a cleaning procedure results in an average loss of one gram per square foot for the sandblasted plates and 6 grams/sq. ft. for those exposed with mill scale. This has been applied as a correction factor in those data which will be subsequently shown. The seven

* Wailes-Dove Hermiston Bitumastic No. 50.

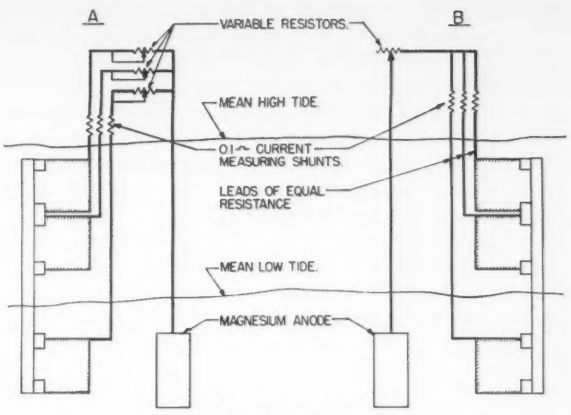

Figure 3—Electrical circuits.

foot bottom plates were weighed as single units where the corrosion attack was general or where there was no indication of corrosion. In some instances where localization of corrosion attack was evident, the plates were cut into 12″ lengths, so that the corrosion rates at these areas could be determined.

Electrical Circuits

In these tests the applied protective currents were furnished by magnesium anodes, employing the two types of circuits shown in figure 3. In figure 3-A each plate is shown to be on a separate circuit, complete with current measuring shunt and a manually operated variable resistance which was used to control the current at the desired value. This circuit was employed in preliminary investigations.

It was soon apparent, however, that such installations were not representative of the conditions prevailing on a continuous piling where the surfaces exposed in the various zones are inter-connected through a low resistance circuit. In order to simulate more closely the conditions which actually exist on a piling, the circuit shown in figure 3-B was adopted for all subsequent installations. In this circuit all of the plates were coupled together electrically through leads of equal resistance, each lead containing a calibrated 0.1 ohm shunt which was used in measuring the flow of current to or from the various plates. This circuit differed from that previously described in that, while the total current to a rack of plates was controlled at some given value, no attempt was made to control the distribution of current between the individual plates. Thus for a 10 plate rack having a total exposed surface of 20 sq. ft. and operating at an applied current equivalent to 5 MA/sq. ft., the total current to the rack was controlled at 100 MA. Since the resistance of the external circuit of each plate was equal, the total applied current was distributed between the individual plates on the basis of solution potentials and the resistances of the internal circuits.

Measurements

In addition to determining the weight losses of the specimens at the conclusion of the tests, periodic

measurements of solution potential and current distribution were made. The current to the various plates was measured by means of a multiple range portable potentiometer connected across the calibrated shunt in the anode to plate circuit. The solution potentials of the various test specimens were measured against a saturated calomel reference electrode. This was equipped with a long salt bridge, the tip of which was bent at right angles so that it could be brought in intimate contact with the plate in question, and thus reduce to a minimum those errors resulting from IR drops through the solution. These measurements were normally made at high tide when all three plates in the tidal zone were immersed.

Test Schedule

The three plate racks were employed in certain preliminary investigations. These investigations indicated that such racks did not simulate piling in seawater, and the longer racks shown in Figures 2-B and 2-C were adopted. The three shorter plate racks were later employed in investigating the effect of paint coatings. The test program is outlined in Table II. With the exception of the uncoupled controls, the electrical hook-up illustrated by Figure 3-B was used.

TABLE II
Test Schedule

Rack No.	Type of Rack	Metal Composition	Surface Condition	Pretreatment	Continuously Applied Current Density M.A./Sq. Ft.
1	10 Plate (Fig. 2B)	Mild Steel	Sandblasted	None	None, Plates Uncoupled
2	10 Plate (Fig. 2B)	Mild Steel	Sandblasted	None	None
3	10 Plate (Fig. 2B)	Mild Steel	Sandblasted	None	5 MA/sq. ft.
4	10 Plate (Fig. 2B)	Mild Steel	Sandblasted	None	10 MA/sq. ft.
5	3 Plate (Fig. 2C)	Mild Steel	Mill Scale	None	None
6	3 Plate (Fig. 2C)	Mild Steel	Mill Scale	Calcareous Coated	None
7	3 Plate (Fig. 2C)	Mild Steel	Mill Scale	Calcareous Coated	3 MA/sq. ft.
8	3 Plate (Fig. 2C)	Mild Steel	Mill Scale	Calcareous Coated	5 MA/sq. ft.
9	3 Plate (Fig. 2C)	Mild Steel	Mill Scale	Calcareous Coated	7.5 MA/sq. ft.
10	3 Plate (Fig. 2C)	Mild Steel	Sandblasted	None	None
11	3 Plate (Fig. 2C)	Mild Steel	Sandblasted	Calcareous Coated	None
12	3 Plate (Fig. 2C)	Mild Steel	Sandblasted	Calcareous Coated	3 MA/sq. ft.
13	3 Plate (Fig. 2C)	Mild Steel	Sandblasted	Calcareous Coated	5 MA/sq. ft.
14	3 Plate (Fig. 2C)	Mild Steel	Sandblasted	Calcareous Coated	7.5 MA/sq. ft.
15	10 Plate (Fig. 2B)	Low Alloy Steel	Sandblasted	None	None, Plates Uncoupled
16	10 Plate (Fig. 2B)	Low Alloy Steel	Sandblasted	None	None
17	10 Plate (Fig. 2B)	Low Alloy Steel	Sandblasted	Calcareous Coated	3 MA/sq. ft.
18	4 Plates	Mild Steel	Sandblasted	None	None, Plates Uncoupled
19	3 Plate (Fig. 2A)	Mild Steel	Sandblasted	None	None
20	3 Plate (Fig. 2A)	Mild Steel	No. 4 Plate Painted	None	None
21	3 Plate (Fig. 2A)	Mild Steel	No. 1 Plate Painted	None	None
22	3 Plate (Fig. 2A)	Mild Steel	No. 1 and 2. Plates Painted	None	None, Plates Uncoupled
23	3 Plate (Fig. 2A)	Mild Steel	No. 1 and 2 Plates Painted	None	None
24	3 Plate (Fig. 2A)	Mild Steel	Painted	None	None
25	3 Plate (Fig. 2A)	Mild Steel	No. 1 and 2 Plates Painted	None	5 MA/sq. ft.
26	10 Plate (Fig. 2B)	Top 3 Plates Monel	Sandblasted	None	None
27	10 Plate (Fig. 2B)	Top 3 Plates Monel	Sandblasted	Calcareous Coated	3 MA/sq. ft.

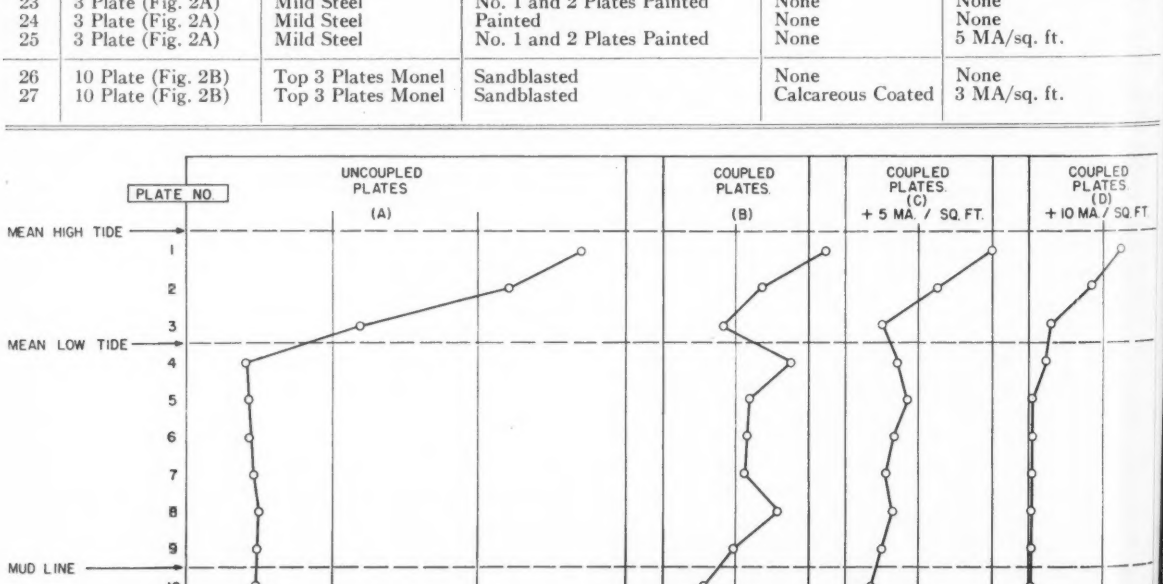

Figure 4—Corrosion rates of mild steel plates in sea water. 6 months exposure.

Discussion and Results

Solution potential measurements made in certain preliminary investigations on uncoupled controls** showed those plates in the tidal zone to be strongly cathodic with respect to the continuously immersed bottom plates. These data indicated that if the three plates were coupled together, a flow of current would be observed, the bottom plate serving as an anode and being sacrificially corroded in an attempt to protect those plates in the tidal zone. In order to determine the effectiveness of this galvanic current, three similar plate racks were installed on which the plates were coupled together through low resistance leads. On this rack the bottom plate was observed to furnish partial protection for the two plates above M.L.T. The corrosion attack experienced by the single continuously immersed plate was considered excessive as the result of the high ratio of cathodic to anodic surfaces. For much the same reason the degree of protection achieved in the tidal zone was believed to be low. The longer racks, having a substantially lower cathode to anode ratio, were therefore adopted.

The corrosion rates observed for the ten plate racks, Nos. 1-4, after approximately six months exposure are shown in Figure 4. The corrosion rates of the uncoupled plates below M.L.T. are considered normal for continuously immersed steel. Above M.L.T. the corrosion attack was very severe, increasing with increasing time of exposure to the atmosphere. When the plates were coupled together the corrosion rates of those plates in the tidal zone were substantially reduced as the result of the protective galvanic currents reduced as the result of the protective galvanic currents furnished by the continuously immersed anodic plates. The corrosion attack below M.L.T. was concentrated on plates 4 and 8 (Figure 6) to furnish the greater part of the protective galvanic current. The application of a protective current equivalent to 5 MA/sq. ft. is shown in Figure 4 to reduce the corrosion attack below M.L.T., particularly on plate 4. There was, however, no significant reduction in the corrosion rates of those plates in the tidal zone. A current equivalent to 10 MA/sq. ft. is shown to reduce very substantially the corrosion rates of the continuously immersed plates. At this current density the corrosion attack on those specimens in the tidal zone was slightly reduced.

Periodic current and solution potential measurements were made on these racks to determine which plates were providing the protective galvanic current and how the applied current was distributed between the various plates. Figures 5, 6, and 7 show the solution potentials and current measurements for a series of plates during a complete tidal cycle under three conditions of exposure. A comparison of the solution potentials of these racks shows that, where the plates were coupled, the galvanic current from the continuously submerged plates effected a substantial increase in the potentials of those plates in the tidal zone. The application of a protective current serves to raise these potentials still higher. There was no significant difference in the solution potentials of the plates below M.L.T. on any given rack.

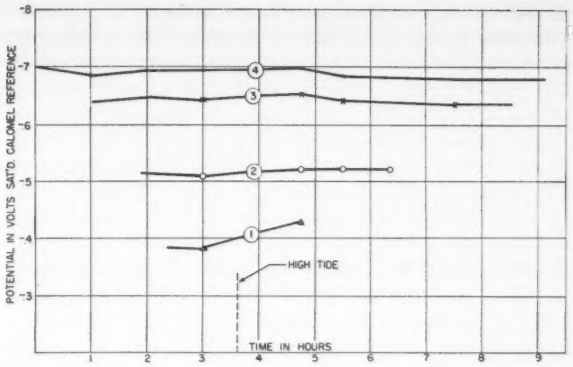

Figure 5—Solution potential measurements during one tidal cycle for uncoupled mild steel plates.

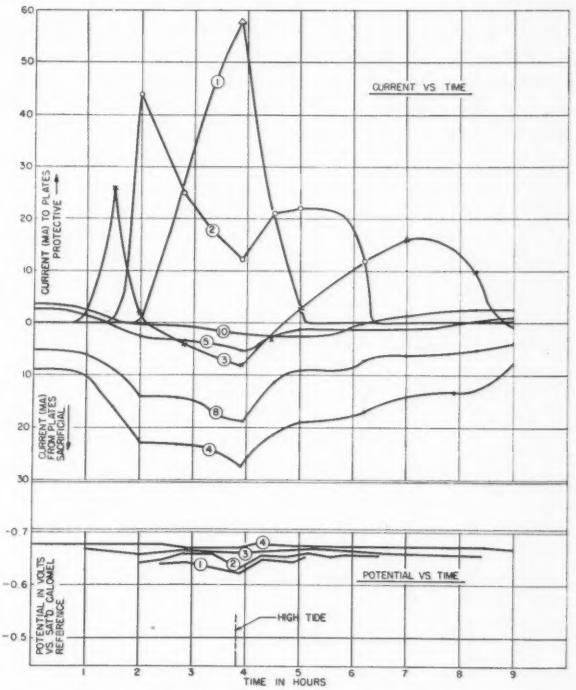

Figure 6—Current and solution potential measurements during one tidal cycle for coupled mild steel plates.

The protective galvanic current on that coupled rack which received no current from an external anode is shown in Figure 6 to be provided principally by plates Nos. 4 and 8. These two plates serve as anodes even during low tide, supplying a protective current to the remaining five continuously immersed plates. No explanation can be offered for the anodic behavior of these plates at this stage of the tide. The behavior of plates Nos. 5 and 10 may be considered representative of the remaining plates below M.L.T. which are now shown. At high tide, all of the continuously submerged plates function as anodes as does No. 3 plate which is located in the tidal zone. Plates Nos. 4 and 8 continue to supply the major part of the protective galvanic current.

** Racks on which the individual plates were not coupled together electrically and which were not connected to external anodes.

The application of a protective current from an external anode is shown in Figure 7 to reduce the amount of current supplied by the continuously immersed bottom plates; these function as anodes for only a short period while the current requirements of the cathodic plates in the tidal zone are at a maximum. A reduction in the sacrificial corrosion attack on those plates below M.L.T. would therefore be anticipated from a study of current flow alone.

Mechanism of the Corrosion Attack on Steel Piling in Sea Water

It is of interest to attempt to explain the mechanism of the corrosion attack which results in the piling profile shown in Figure 1 on the basis of these observations. In Zone 1 wetting occurs only during periods of abnormally high tides and the surface of the steel is usually dry. The corrosion attack is stifled by the lack of moisture and the corrosion rate decreases with decreasing frequency of wetting. The surfaces exposed in Zone 2 are also normally exposed to the atmosphere. In this splash zone, however, wetting occurs at such a frequency that the corrosion products on the surface of the steel are probably never completely dry. In the presence of moisture and a plentiful supply of oxygen the local corrosion cells are very active at all times. The corrosion attack under such conditions and in the absence of any periodically applied protective galvanic current is very severe. This is shown by the high corrosion rates observed for the alternately immersed uncoupled plates in these tests.

The similarity of the corrosion attack in Zone 3 to that observed for the alternately immersed coupled test plates is evident. In this zone the corrosion attack is believed to occur primarily during periods of atmospheric exposure. The continuously immersed portions of the piling are shown to serve as anodes providing a substantial degree of protection for those surfaces in the tidal zone. As would be expected the effectiveness of the protective current increases with increasing time of submergence. The protective action of these galvanic currents is probably due in part to an increase in pH of the water film immediately adjacent to the metal surface which may under certain circumstances precipitate a calcareous coating. If such coatings are hard and continuous they afford a considerable degree of protection to the underlying metal. In Zone 4 the continuously immersed surfaces of the piling are sacrificially corroded as the result of the high current demands of those areas in the tidal zone. The galvanic corrosion attack is normally concentrated at a point just below M.L.T. probably as the result of its close proximity to the strongly cathodic surfaces and the corresponding lower resistance of the internal circuit.

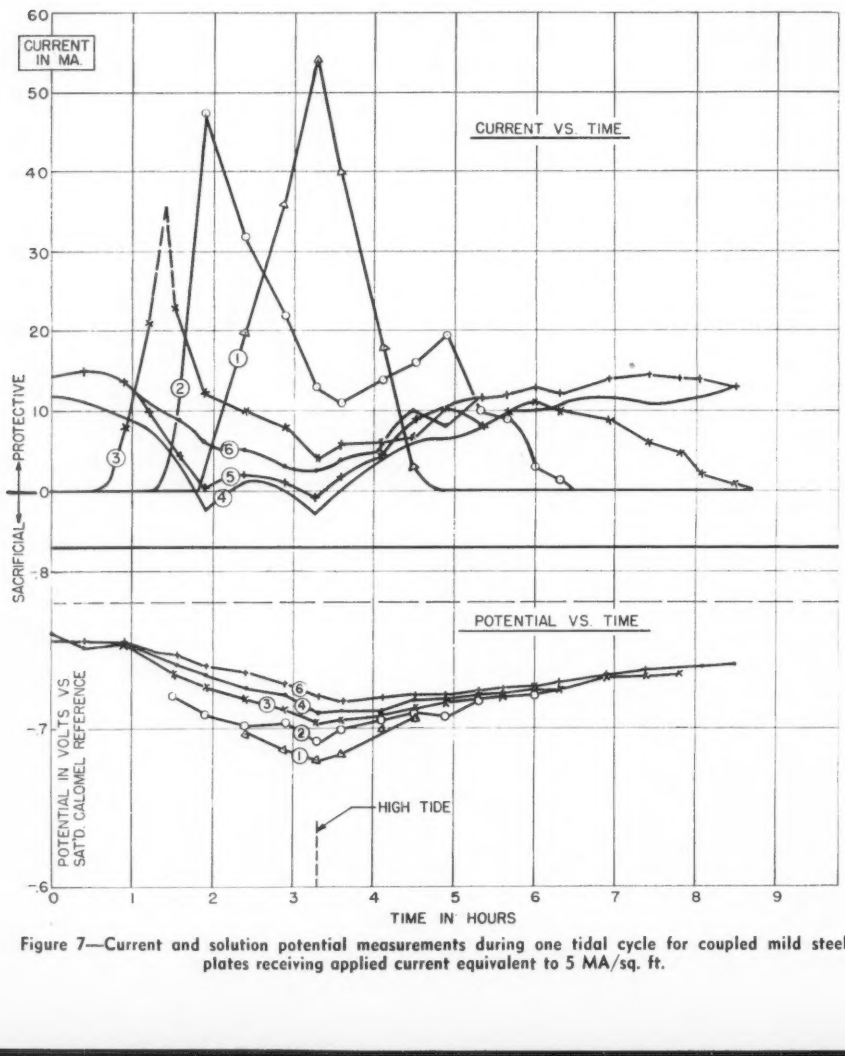

Figure 7—Current and solution potential measurements during one tidal cycle for coupled mild steel plates receiving applied current equivalent to 5 MA/sq. ft.

Effect of Calcareous Coatings

Previous work has shown that the initial application of a high current density for a period of approximately 5 days served to polarize continuously immersed steel specimens to a protective solution potential and lay down a calcareous coating which affords a considerable degree of protection to the underlying metal for short periods of time. After such a coating has been deposited the continuous application of a current density of 3 MA sq. ft. was found to give virtually complete protection. In order to determine the effectiveness of these coatings on structures such as marine piling where varying conditions of exposure are encountered, racks Nos. 5-14 were exposed.

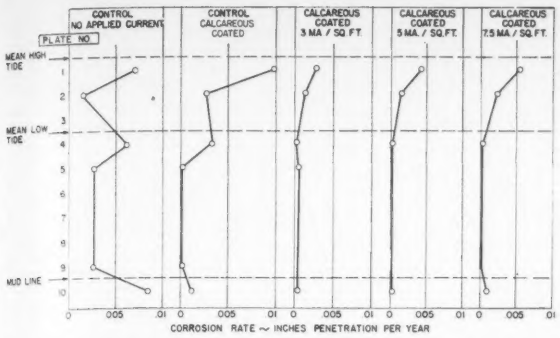
CONTROL NO APPLIED CURRENT
CONTROL CALCAREOUS COATED
CALCAREOUS COATED 3 MA / SQ FT
CALCAREOUS COATED 5 MA / SQ FT
CALCAREOUS COATED 7.5 MA / SQ FT
PLATE NO
MEAN HIGH TIDE
MEAN LOW TIDE
MUD LINE
CORROSION RATE ~ INCHES PENETRATION PER YEAR

Figure 8—Corrosion rates of mild steel plates with mill scale, 291 days exposure.

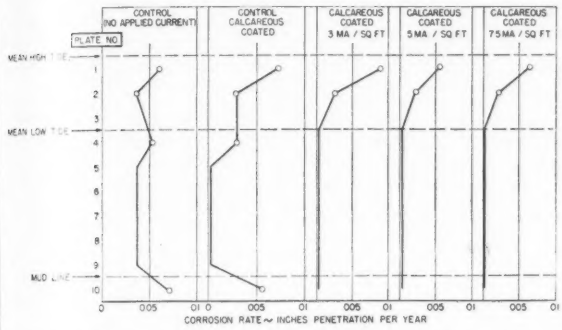
CONTROL (NO APPLIED CURRENT)
CONTROL CALCAREOUS COATED
CALCAREOUS COATED 3 MA / SQ FT
CALCAREOUS COATED 5 MA / SQ FT
CALCAREOUS COATED 7.5 MA / SQ FT
PLATE NO
MEAN HIGH TIDE
MEAN LOW TIDE
MUD LINE
CORROSION RATE ~ INCHES PENETRATION PER YEAR

Figure 9—Corrosion rates of sandblasted mild steel plates, 352 days exposure.

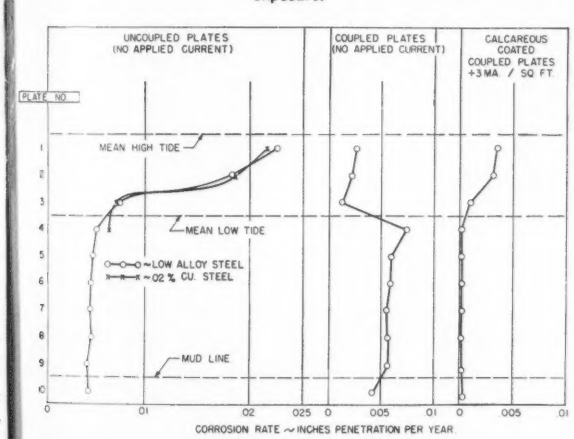
UNCOUPLED PLATES (NO APPLIED CURRENT)
COUPLED PLATES (NO APPLIED CURRENT)
CALCAREOUS COATED COUPLED PLATES +3 MA / SQ FT
PLATE NO
MEAN HIGH TIDE
MEAN LOW TIDE
~LOW ALLOY STEEL
~02 % CU. STEEL
MUD LINE
CORROSION RATE ~ INCHES PENETRATION PER YEAR

Figure 10—Corrosion rates of "low alloy" steel plates, 83 days exposure.

Plates With Mill Scale

The corrosion rates for the plates with mill scale on racks Nos. 5-9 after 291 days exposure are shown in Figure 8. The corrosion attack on the continuously immersed plates of the uncoated control is shown to have been concentrated at points just below mean low tide and below the mud line. This group of racks were inadvertently installed in a location where sewage from The Ethyl Dow Chemical Co. had been previously discharged. It is suspected that the concentrated corrosion attack observed below the mud line may be attributed to the presence of a layer of this accumulated sewage. A similar distribution of corrosion below M.L.T. was observed on that rack containing the coated controls, although the rate of corrosion was considerably lower. The center sections of this bottom plate are shown to have received excellent protection from the calcareous coating. In the tidal zone, however, the corrosion rate of the bare control was appreciably lower than that of the calcareous coated control. The application of low protective currents to the coated racks is shown to substantially reduce the corrosion rates of those specimens exposed in the tidal zone, and to virtually eliminate corrosion below M.L.T., including those areas below the mud line. These data imply that the application of cathodic protection will be equally effective in the sub-soil exposure of Zone 5.

Sandblasted Plates

The corrosion rates for the sandblasted plates on racks Nos. 10-14 after 352 days exposure are shown in Figure 9. In general the corrosion profiles for these racks are comparable to those shown in Figure 8 for similar plates with mill scale. From a comparison of these data it would appear that, at a given current density, a greater degree of protection can be achieved in the tidal zone where the mill scale is left intact. A comparison of Figs 4 and 9 indicates that while calcareous coatings are less beneficial under conditions of alternate immersion, even here a greater degree of protection can be achieved at a given current density if such a coating is initially applied. It has been observed, however, that under certain conditions which cannot as yet be clearly defined, the presence of calcareous coatings on those surfaces exposed in the todal zone tend to accelerate the corrosion attack. Previous work[1] has shown that coatings formed by the continued application of high current densities are thick, soft, and have an appreciably greater porosity. Under conditions of alternate immersion they might be expected to serve less as a protective coating and more like a wick, retaining appreciable amounts of water during periods of atmospheric exposure, and thus increase the time required for drying.

Effect of Metal Composition on the Corrosion Rate in the Tidal Zone.

The corrosion rates observed for the uncoupled test specimens as shown in Figure 4 were considerably higher than were anticipated. It was suggested that such corrosion rates might result from the use of a steel which was either excessively dirty or very low in copper, assuming the copper content to be as critical under conditions of alternate immersion as it has been shown[2] to be in atmospheric exposure. This material (composition A) was shown to be low in copper.

The corrosion rates of the "low alloy" steel plates on racks Nos. 15-17 are shown in Figure 10 for 83 days exposure. A similar rack (No. 18) containing composition "A" specimens was included for purposes of comparison. The corrosion rates of the two types of steel are shown to be practically identical on the uncoupled racks. These data suggest that, as in the case of continuous immersion,[3] the addition of small amounts of alloying elements has no significant

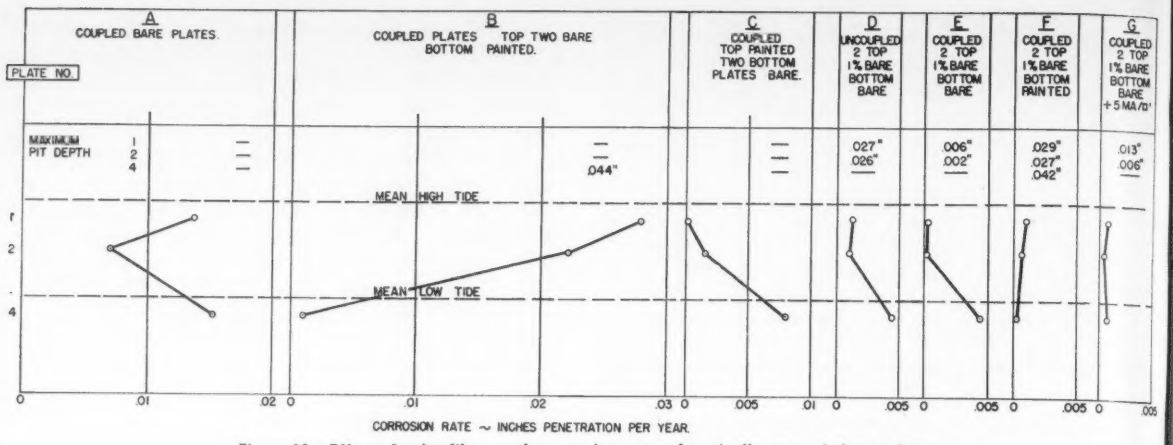

Figure 11—Effect of paint films on the corrosion rates of vertically suspended test plates.

effect on the corrosion rate of uncoupled steel in the tidal zone. It is recognized that this observation is based on tests of short duration and that longer periods of exposure might show a considerable difference between these compositions. When the plates are coupled together the beneficial effect of the protective galvanic current provided by the continuously immersed plates is evident, the corrosion rates of the two upper plates in the tidal zone having been reduced to approximately 1/10 that of similarly exposed uncoupled specimens. The application of a current density equivalent to 3 MA/Sq. Ft. to calcareous coated plates is shown to give virtually complete protection below mean low tide. The corrosion rates of the test plates in the tidal zone, however, are slightly higher than those of the corresponding plates on the coupled rack to which no protective current was applied. It will be noted that the protective current, either galvanic or from an external anode, affords a much greater degree of protection to plates exposed in the tidal zone in the case of the "low alloy" steel. On the basis of the limited data now available, this is presumed to indicate that in this zone such a steel can be more readily protected cathodically than low copper steel (composition A).

The Use of Protective Coatings in the Tidal Zone

The effectiveness of cathodic protection has been shown to decrease with increasing time of exposure to the atmosphere, ranging from zero in the splash zone above high tide to complete protection below M.L.T. if proper current densities are employed. Of most concern is the region comprising the upper third of the tidal range and all of the splash zone above high tide since here the corrosion attack is most severe and cathodic protection least effective. Figure 1 shows that initial failure will occur at some point in the splash zone. The life of existing piling will therefore not be increased even where complete protection is achieved below mean high tide unless those surfaces at and above the high water line are given additional protection in the form of coatings such as paint, concrete, or metal sheathing.

In order to determine the effectiveness of coatings in the tidal zone, racks Nos. 19-25 were prepared and installed. The corrosion rates observed after 180 days exposure are shown in Figure 11. The normal corrosion profile for a three plate coupled rack of unpainted test specimens is shown in Figure 11-A. The corrosion rates both above and below mean low tide are high as the result of the high ratio of cathodic to anodic areas. Figure 11-B gives the corrosion profile of a coupled three plate rack, the two plates in the tidal zone being bare and the bottom plate painted. Due to its protective coating, the bottom plate is unable to provide an appreciable protective current, and the corrosion rates of those plates in the tidal zone are correspondingly high, being comparable to uncoupled plates. While the weight loss of the bottom plate was quite small, severe pitting occurred at breaks in the paint film where the whole of the galvanic corrosion attack was concentrated. Figure 11-C shows the corrosion rate of a three plate coupled rack on which the top plate was painted. The reduction in the ratio of cathodic to anodic surfaces served both to increase the protective current density on the single cathodic plate in the tidal zone, and to reduce the galvanic corrosion attack below M.L.T. Figure 11-D shows the corrosion rate of a three plate uncoupled rack, the two top plates being 1% bare, and the bottom plate unpainted. Corrosion rates for a similar coupled rack is shown in Figure 11-E. A comparison of Figure 11-D and 11-E shows that the corrosion attack on the bottom continuously immersed plate was not increased by coupling, since, due to the presence of the protective coating in the tidal zone, the ratio of cathodic to anodic surfaces is low. The corrosion rates and particularly the severity of pitting of those plates in the tidal zone was reduced on the coupled rack. Figure 11-F gives the corrosion rates of a three plate coupled rack on which the two top plates were 1% bare while the bottom plate was completely painted. The weight losses for these plates were low, but the pitting was quite severe at breaks in the paint coating on all three plates. Figure 11-G shows the corrosion rates for a three plate coupled rack to which a current of 30 MA, equivalent to 5 MA/sq. ft., was applied. On this rack the two top plates were 1% bare and the bottom plate was completely bare. The applied current served to reduce the corrosion rates on all three plates to very low values. The severity of pitting in

the tidal zone was slightly greater than for a similar coupled rack (Figure 11-E) which received no applied current. This is attributed to the heavy, porous, moisture retaining, calcareous deposits formed at the exposed areas by the extremely high current densities.

These data on the use of protective coatings in the tidal zone show that they are effective not only in protecting that area over which they are applied, but also substantially reduce the galvanic corrosion attack below M.L.T. Where cathodic protection is used in conjunction with properly maintained paint films in the tidal zone, corrosion can be virtually eliminated. The use of protective coatings in the tidal zone serves in addition to simplify the application of cathodic protection, particularly where the ratio of surface exposed in the tidal zone to that continuously immersed is high.

There was some concern over the possibility that paint films in the tidal zone might be damaged by the caustic produced as a result of either the galvanic or the applied currents. An inspection of the test plates indicated that such was not the case, the coatings on the uncoupled plates being in considerably poorer condition than those coatings on plates receiving a protective current.

Use of Metal Sheathing in the Tidal Zone

It has been suggested[4] that some corrosion resistant metal, such as nickel or Monel, might be advantageously used to clad or sheath those surfaces exposed in the tidal zone. Such coatings would have the obvious advantage of permanence. However, due to the more noble potentials of these metals, it seemed probable that the sacrificial corrosion attack on the anodic surfaces below mean low tide would be accelerated. In order to determine the performance of such an installation, racks Nos. 26 and 27 were exposed on which Monel plates were mounted in the upper three positions, these being coupled to the seven continuously immersed mild steel bottom plates. The corrosion rates of these racks after 83 days exposure are shown in Figure 12. The corrosion rates of those plates below mean low tide on that rack to which no current was applied (No. 26) were, if anything, slightly lower than for a similar rack having steel plates in the tidal zone (Figure 10). The fact that no increase in corrosion was observed for those continuously immersed steel plates coupled to Monel plates located in the tidal zone is indicative of the highly cathodic behavior of steel plates under conditions of alternate immersion in seawater. The Monel plates showed no loss in weight and no pitting.

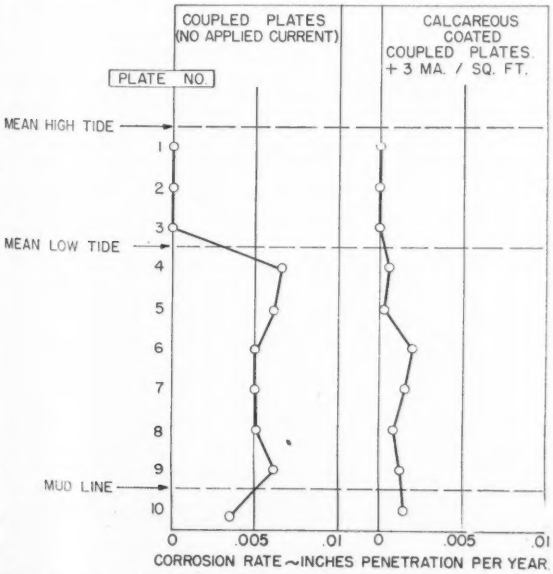

Figure 12—Corrosion rates of mild steel plates coupled to monel plates mounted in the upper three positions.

The rack to which a protective current was applied is shown to have experienced some corrosion attack below M.L.T. No explanation can be offered for the failure to obtain the same degree of protection in this zone as was observed for a similar 10 plate rack containing all steel specimens. Current distribution measurements failed to reveal any abnormal drain of current to the Monel plates in the tidal zone and it is suspected that this test rack inadvertently failed to receive the desired current during the 5 day period of initial polarization. It is believed that complete protection can be effected for a structure of this type where Monel clad or sheathed steel is used in the tidal zone.

Summary and Applications

The corrosion rate of alternately immersed, uncoupled steel specimens in sea water is shown to be very high and to increase with increasing time of exposure to the atmosphere. The nature and severity of the corrosion here observed is believed to be comparable to that experienced by a piling in the splash zone above high tide. The corrosion attack for similarly exposed coupled plates is considerably modified as the result of the protective galvanic current furnished by the continuously immersed surfaces. The corrosion attack on these surfaces below M.L.T. is accelerated by this galvanic effect. Cathodic protection is of no value in the splash zone, and only partially effective in the tidal zone. Below M.L.T. the corrosion attack can be virtually eliminated by the application of a protective current equivalent to 3 MA/Sq. Ft. after the initial deposition of a calcareous coating.

Since initial failure will occur in the splash zone, cathodic protection will not prolong the life of steel piling unless protective coatings are applied beginning at some point above the splash zone and extending down below the high water line. The nearer such coatings can be applied to M.L.T., the greater their effectiveness.

There are many possible methods by which the life of steel piling in sea water might be extended. Several of these are listed below in what is believed to be the order of increasing effectiveness.

1. *The Application of Paint Coatings to Continuously Submerged Surfaces Only*

This condition is included as an example of how

coatings might be used to accelerate the failure of such a structure. Since the continuously immersed section would not provide the galvanic protection for the tidal zone, the corrosion attack there would be comparable to that of the uncoupled controls and would probably exceed that experienced in the splash zone. Below mean low tide the galvanic corrosion attack would be very severe at any breaks in the paint film.

2. *Bare Piling*

Failure would be expected to occur in the splash zone above high tide in accordance with Figure 1.

3. *The use of Monel sheathing above M.L.T.*

An installation of this type would serve to change the point of initial failure to that area just below M.L.T. and the life of the piling would be increased. The corrosion rate of the continuously immersed section of ordinary steel would not be accelerated over that of bare piling since Monel apparently becomes no more cathodic than ordinary steel under conditions of alternate immersion.

4. *The Application of Protective Paint Coatings Above Mean Low Tide Only*

The painting of those strongly cathodic areas above mean low tide would greatly reduce the sacrificial corrosion attack on the continuously submerged section. Failure could eventually occur at any point below M.L.T. A substantial degree of protection would be afforded exposed areas in the tidal zone where breaks in the paint film occurred without any significant increase in the corrosion attack below M.L.T.

5. *Use of Painted Monel Sheathing Above M.L.T.*

The corrosion rate below M.L.T. would be the same as in No. 4. This system would have the advantage of eliminating pitting at breaks in the paint coating.

6. *Paint Surfaves Above M.L.T. and Apply Cathodic Protection*

This would provide complete protection for the continuously submerged surfaces. Above M.L.T. a slight pitting would be predicted at breaks in the paint coating.

7. *The Use of Monel Sheathed Steel Above M.L.T. + Cathodic Protection*

Such an installation would provide complete protection both above and below mean low tide. The application of paint coatings in the tidal zone would reduce the current requirements for protection.

Acknowledgment

The author wishes to acknowledge the kind assistance of Mr. H. A. Robinson of this laboratory for his many helpful suggestions both with regards to the experimental program, and in the preparation of this paper. Special thanks are due Mr. W. H. Moore of The Ethyl Dow Chemical Company for his assistance in conducting these tests.

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2. D. M. Buck, "Copper in Steel—The Influence on Corrosion." *Ind. Eng. Chem.* **5,** 447 (1913).
3. C. P. Larrabee, "Corrosion of Steel in Marine Atmospheres and in Sea Water." *Trans. Electrochem. Soc.* **87,** 161 (1945).
4. F. L. LaQue, Private Communication.

DISCUSSION

Comment by George C. Cox, Consulting Engineer, Charleston, West Virginia:

Humble's investigation of the cathodic protection of steel piling in sea water shows that the use of cathodic protection below low tide will decrease the corrosion of steel to a negligible and comparatively low corrosion rate. Streever states that his work at Newport News is in agreement with and confirms Humble's findings.

Humble further concludes that the effective and economic use of cathodic protection in the tidal zone can only be obtained in conjunction with protective coatings such as paint, concrete or a sheath of a suitable sea water corrosion-resistant alloy. I believe that the recent findings of the other investigators in this field are also in agreement with these conclusions of Humble.

As suitable paints are available for use above high tide, the present problem is to reduce the corrosion rate of steel piling in the tidal zone to a rate comparable to the rate below low tide when using cathodic protection.

There is ample need for the various types of coating or sheathing material for marine piling in order to meet specific engineering requirements. Therefore, the writer wishes to discuss briefly one such type which appears to have some advantages for marine piling protection not found in other coating materials.

This discussion is based on the writer's investigations and includes tests on mild steel strips, which extended above and below the tidal zone in Cuban waters, and maintenance tests on a tug having no paint on the wind-water or submerged hull areas which it was in daily operation in English waters.

For a magnesium-cement type of coating having the greatest protective value, the ratio of magnesium to calcium compounds must be within limits which will give a mixture of low porosity. These low porosity mixtures can be electroplated directly on a steel marine structure from the surrounding sea water at cathodic current densities between 100 and 400 milliamperes per square foot. Such dense coatings will require a minimum cathodic protection current to maintain good protection of the steel surface after a sufficient amount of the mixture is deposited. Sand blasted mild steel test panels treated in this way, but with no cathodic protection during the test period, were still perfectly protected after seven months in South Hampton harbor waters. When the current density is reduced below 50 milliamperes per square foot, the cement mixtures become more porous and require an increased amount of cathodic maintenance current to protect the increased amount of effective bare surface area.

When the current density on a clean steel surface is increased above 400 milliamperes per square foot, the spalling and exfoliation increase markedly and soon become so great that little useful coating remains on the treated surface. Under such conditions the cathodic maintenance current required to prevent corrosion becomes increasingly greater.

At the optimum current densities a sufficient

amount of the magnesium-cement coating is usually deposited after the expenditure of 4 to 10 ampere hours per square foot. The writer has built up a concrete-like mass around steel panels which were held in the sand-water scouring zone of a beach having a medium surf. This was done by allowing sand particles to become embedded in the cement mixture while the electroplating operation was going on.

An interesting possible application of these magnesium-cement coating mixtures is to reduce the erosion of steel groins such as those discussed by Mr. Ross in his paper on the Palm Beach installation.

Discussion by C. P. Larrabee* and F. L. LaQue, presented orally during the Cincinnati NACE meeting on April 14, 1949:**

It is not often that one has the privilege of being even remotely associated with the beginnings of an industry. Mr. Humble's excellent paper seems to provide the fundamental information upon which may grow the cathodic protection of a great many steel structures immersed in sea water. These may range from off-shore oil well drilling rigs and large steel piers to ships in storage.

During a discussion at Kure Beach, N. C., in June, 1948, of some of Mr. Humble's preliminary results, it was decided by the authors to make a cooperative test to confirm his findings with regard to the differences in corrosion rates between insulated steel specimens and those electrically connected when both types were exposed below low tide, in the tidal zone, and above high tide.

A plate of structural carbon steel 3/16 by 48 by 144 inches was sheared into two 12-inch-wide strips and several 12-inch-square pieces. These were mounted on wooden racks with porcelain insulators as shown in Figure 1 and placed in the basin at Kure Beach so that the upper 26-inch portion was above the average high tide.

After five months of exposure the rusts on areas of corresponding heights above low tide had very dissimilar appearances as seen in Figure 2. Rough-appearing rust is a good indication of severe corrosion underneath. The amount of sulfate sulfur in

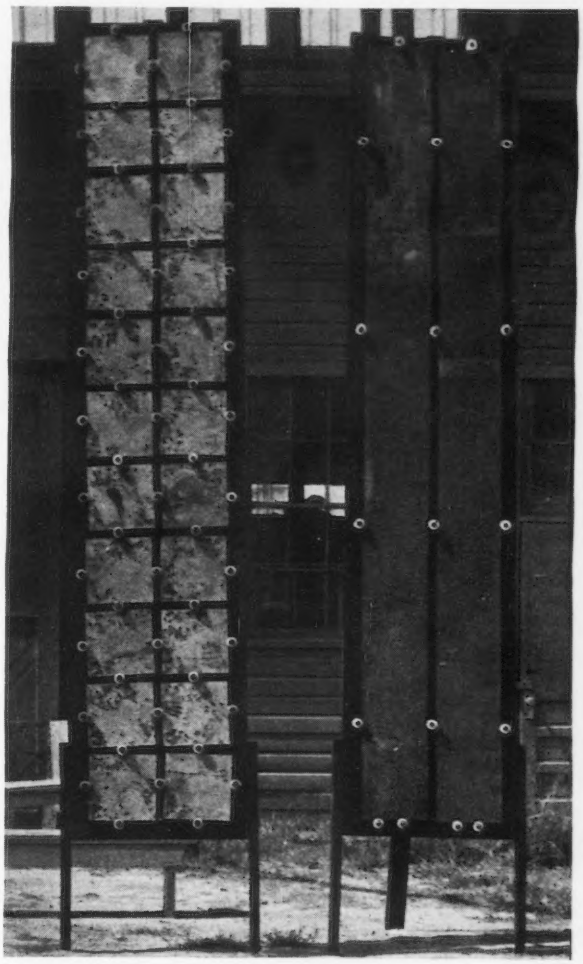
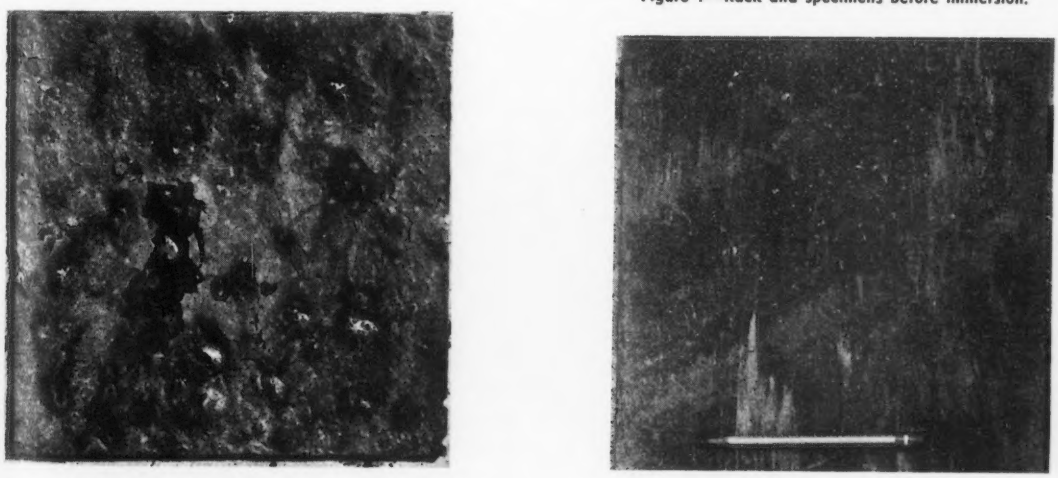


Figure 1—Rack and specimens before immersion.



Individual specimen 4th from top. Comparable area of 12-foot long strip.

Figure 2—Difference in appearance of rust on steels exposed between high and low tides.

* Research Laboratory, Carnegie-Illinois Steel Corporation.
** Corrosion Engineering Section, International Nickel Company.

the two rusts were the same (0.08 percent); however, the amount of sulfide sulfur in the rust from the individual specimen was over five times that in the rust from the strip, i.e. 0.28 vs. 0.05 percent. We have no explanation of this phenomenon.

This test offers further proof that the appearance of the rust is an indication of the amount of corrosion. After the five months of exposure, one strip and one vertical row of square specimens were removed, cleaned of rust, and reweighed. The 12-foot strip was cut into eleven pieces, each 13.1-inch long, in order to correspond in location with the square specimen and separating insulator. The average penetration calculated from loss of weight of each piece from the strip and each 12-inch-square specimen is shown in the right side of Figure 3. For ready comparison, these values are plotted on the left side on the same figure.

It is evident that these data agree with Mr. Humble's in that: a) the corrosion of the strip in the tidal zone is much less than that of individual specimens in this location, b) the lowest corrosion rate of the strip occurs immediately above low tide, c) the most severe corrosion is just above high tide, and d) the continually submerged portion of the strip is corroded slightly more than the corresponding individually exposed specimens. It is obvious that tests of relatively small specimens of steel exposed in the tidal zone only will not give data useful in predicting the life of steel piling in this zone.

The major difference between Mr. Humble's results and ours is the substantially greater attack found by him on the specimen electrically connected to the others and which was exposed just below low tide. No logical explanation can be advanced for this difference.

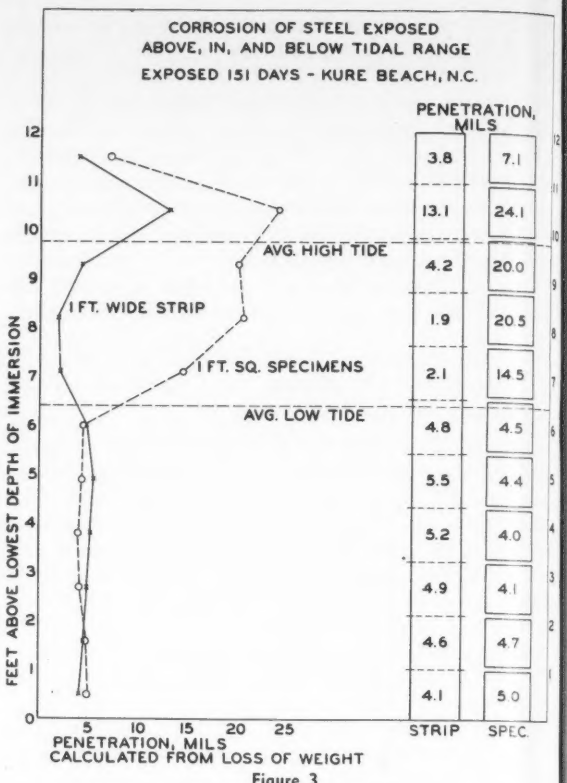


Figure 3

We plan to remove the remaining set of samples in 1951 after two years of exposure. Possibly at that time the differences in the corrosion at the various locations will be more pronounced and more conclusive data on the relative amount of corrosion at increasing distances below low tide will be obtained.

NACE REPRINT PRACTICE

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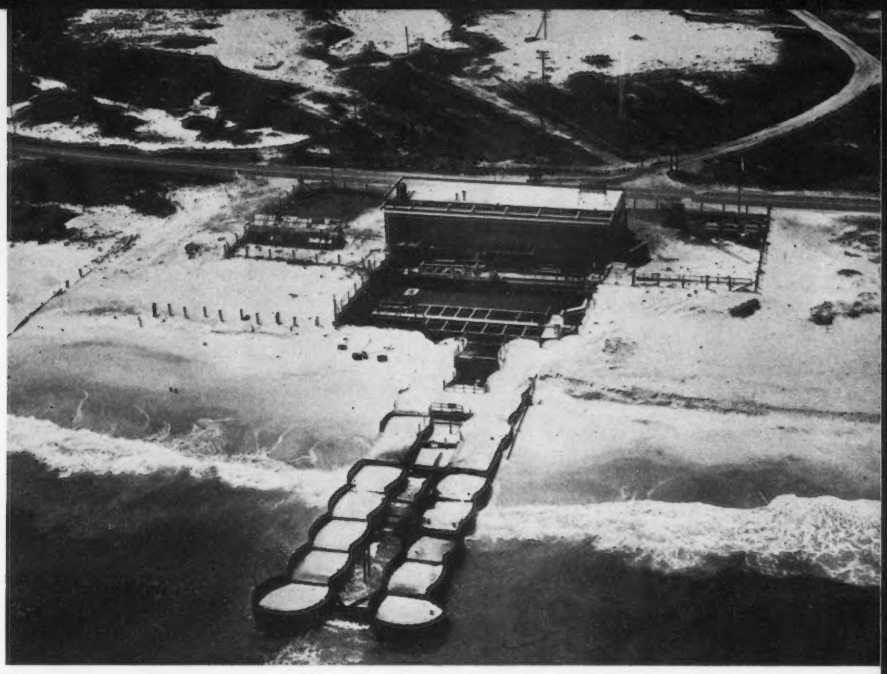


Figure 1—Air view of corrosion testing station, Kure Beach, North Carolina.

Corrosion Testing Facilities At Kure Beach, North Carolina*

By IVY M. PARKER*

THE SEA WATER corrosion testing station at Kure Beach,[1] established by the International Nickel Company in 1935, continues to provide answers to many baffling sea water and marine atmosphere corrosion problems.

Because of the great interest in the progress of the work, some 250 representatives of industry, university, and government gather for the Sea Horse Institute in early June of each year for three days of inspection and extemporaneous discussion. The deficiencies in existing information are brought out, and tests are devised for supplying the needed information.

Technical and maintenance staffs are kept busy the year around. These are reinforced periodically by the research personnel of the many participating industries and government departments.

Figure 1 shows an air view of the test basin and pump house with the eighty-foot atmospheric spray test racks to the left of the pump house and the laboratory and museum building in the upper right hand corner. Figure 2 shows the eight-hundred-foot atmospheric test lot which is located to the right of the road leading from the pump house to the laboratory.

★ Voluntarily submitted for publication July 15, 1949.
* Research Engineer, Plantation Pipe Line Company, Bremen, Ga., Editor of CORROSION.

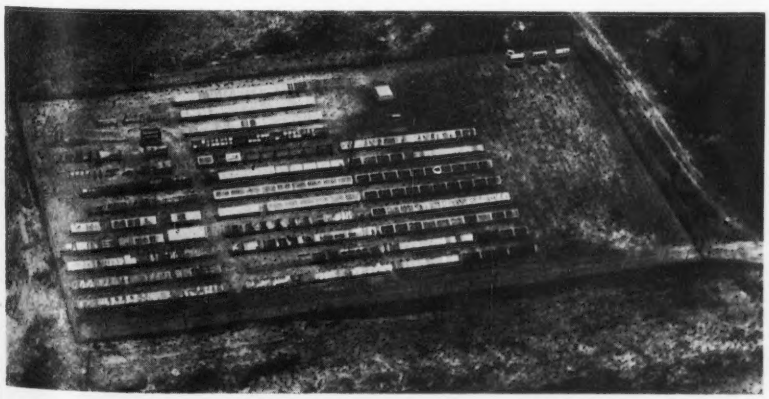


Figure 2—Air view of 800-foot atmosphere test lot.

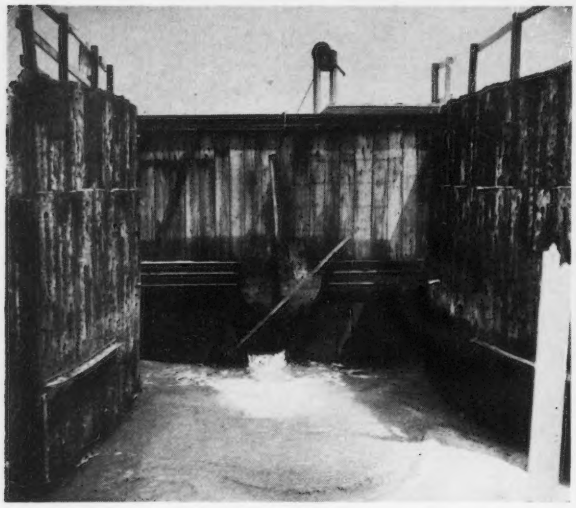


Figure 3—Close-up of inlet.

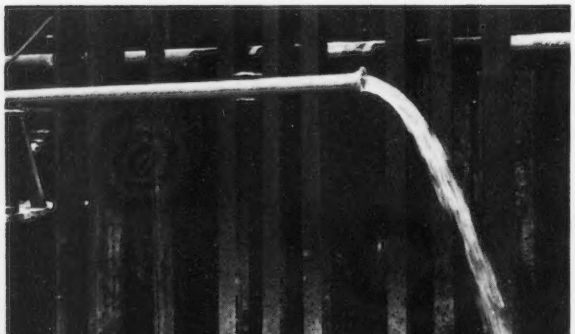


Figure 4—Close-up of piling test.

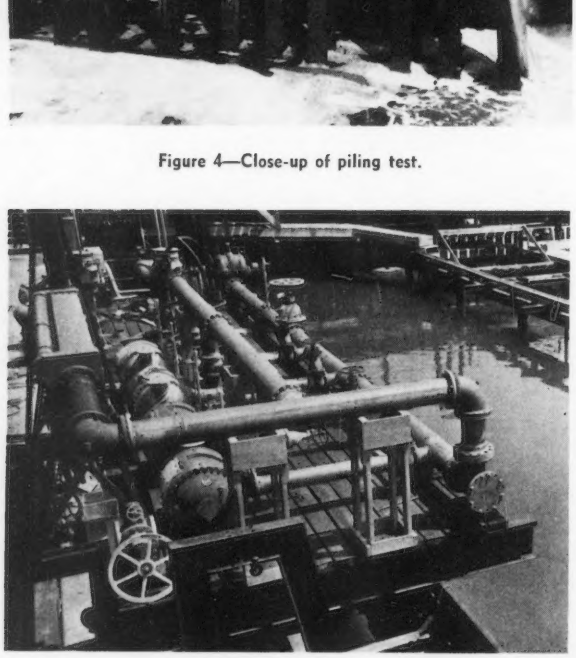


Figure 5—Full-scale test of heat exchanger and model units.

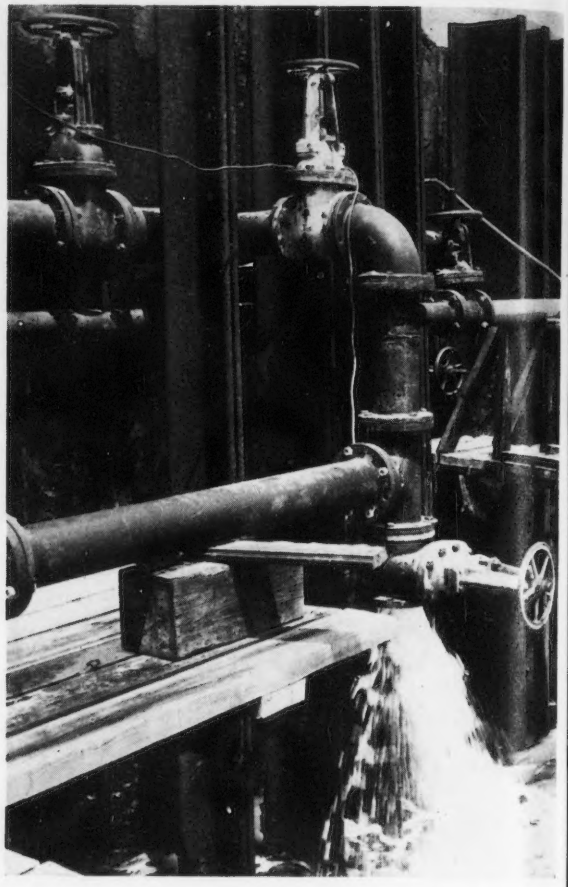


Figure 6—Sea water bypassed to basin from full-scale oil cooler test.

Fresh, clean sea water flows in and out of the test basin through a forty-two inch flume. (See Figure 3). This figure shows the low and high tide levels. The steel pilings around the test basin serve not only as walls to the basin but as test pieces as well. These are inspected periodically, and a record of the rate of corrosion is maintained. Other piling tests (see Figure 4) are in process. In line with increased interest in the use of steel piling, a large amount of work is being carried out in developing cathodic protection for such installations. As an outgrowth of the development work done at Kure Beach, some 300,000 pounds of magnesium were sold last year for cathodic protection of steel piling. High purity magnesium is very superior to impure magnesium for cathodic protection in sea water. Incidentally, cathodic protection is effective only in areas covered by water. Paint or other means of protection has to be used at tide line and above.

An outgrowth of the development of cathodic protection for steel piling with magnesium anodes is the present experimental installation of cathodic protection on the hull of one of the ships in the "Moth Ball Fleet." Preliminary tests indicate that these ships can be completely protected at a cost of two to three cents per square foot per year. The installation is designed and tested to give a potential of 0.8 volt between the metal and a saturated calomel

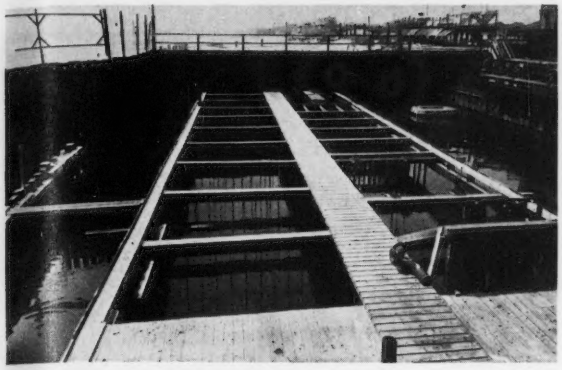


Figure 7—Test basin.

half cell. Approximately three milliamperes of current per sq. ft. are needed. This protection, if successful, will eliminate periodic dry docking for cleaning and painting of the large number of ships which are idle but which must be kept in good order. Experiments are in progress to test the effect of velocity on the current required to obtain cathodic protection. Early tests show a sharp rise in current required to get protection in flowing sea water.

An extensive program for testing the cathodic protectiion of oil coolers with zinc plates has been installed by the Navy. This test provides for the circulation of 1500 gpm of sea water through four oil coolers and back into the basin as shown in Figures 5 and 6. Water circulates around tubes. A continuous record of the current output of each set of zincs is kept. Potential readings between various parts of unit and calomel half cell are made daily. Auxiliary laboratory scale units have been set up to determine effect of velocity and effective distance or carrying power of zincs. Experiments using zinc for cathodic protection in sea water have shown 99.99% pure zinc to be far superior to 99.9% zinc. Results indicate that a zinc which has dropped in efficiency because of scaling can be revived by applying an external current to dislodge at least a portion of the scale.

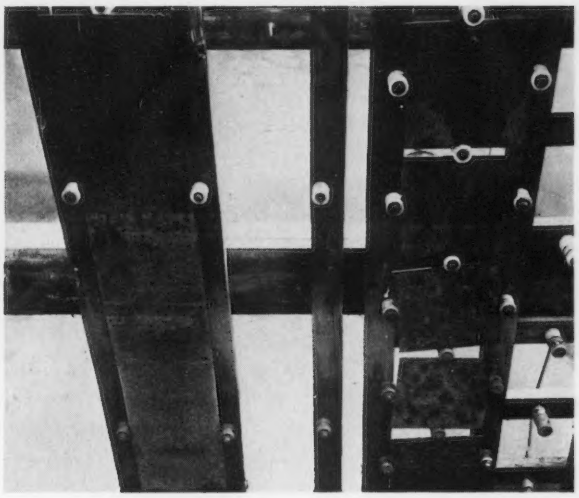


Figure 9—Tidal exposure of continuous and interrupted steel specimens in sea water.

Figure 10—Examining effect of velocity and sea water corrosion.

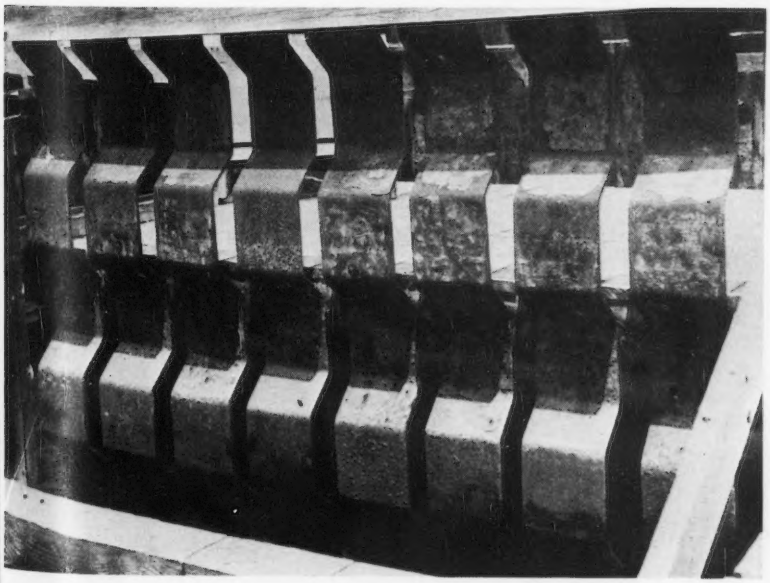


Figure 8—Close-up of tank section.

Figure 7 shows the section of the test basin devoted to the study of the corrosion of metals and the stability of coatings in quiet sea water as well as the action of antifouling organisms. A second fouling test station, which is less sheltered, has been installed at Wrightsville Beach, which is about 10 miles up the coast.

Other tests in the basin include exposure of bent strips of ship steel (Figure 8), and tests to compare the corrosion rate on continuous lengths of sheet steel ex-

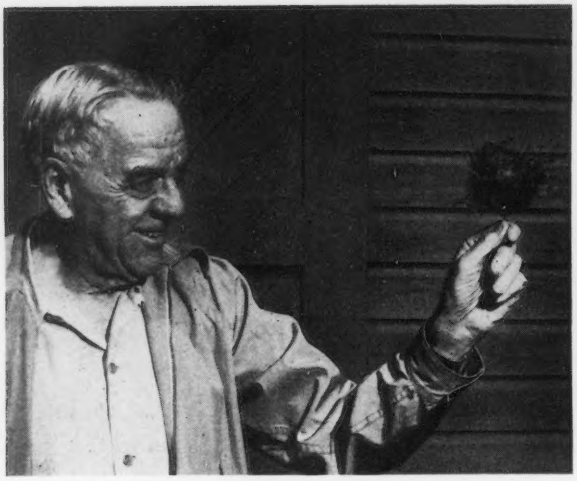


Figure 11—Hair grown on a billiard ball.

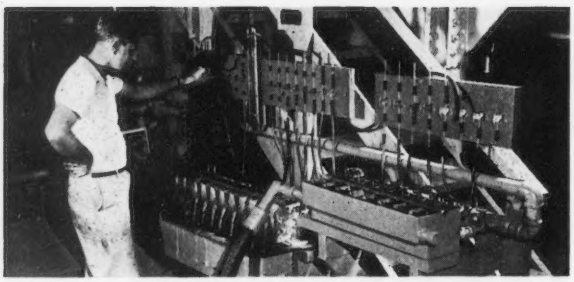


Figure 12—Jet test apparatus.

posed at tide level and below with the same amount of steel cut in short sections and similarly exposed. The short sections (Figure 9) suffer a much greater over-all corrosion rate than does a single strip. An explanation of this phenomenon will be found in Hilary Humble's paper in this issue of CORROSION.

The pump house has been converted into an extensive laboratory where metal specimens are subjected to flow velocities up to 27 feet per second as well as exceptionally high rotational speeds with or without air. Figure 10 shows a short section of the over 300 feet of troughs carrying water flowing at about three feet per second. A large number of short metallic specimens as shown, as well as wood and other organic materials, are exposed in these troughs. A billiard ball exposed in sea water grew "hair" as shown

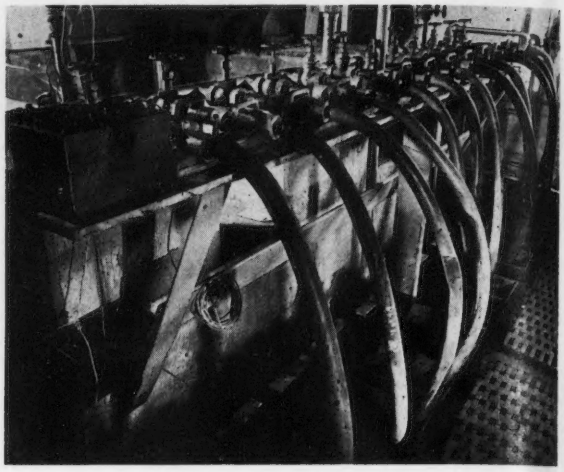


Figure 13—High speed galvanic tester.

in Figure 11. The gentleman in this picture is Dr. William F. Clapp, noted marine biologist and popular speaker at the NACE 1949 banquet in Cincinnati.

The jet test apparatus (Figure 12) tests the effect of a stream of water mixed with air striking directly against a piece of metal submerged in flowing sea water. This test guided the development of a cupro nickel containing 0.8 to 1.5% iron to produce a superior condenser tubing.

The newest laboratory test apparatus at Kure Beach is the Galvanic Tester (Figure 13). This apparatus carries water at velocities up to fifteen feet per second. It originally was set up to measure the current generated between two metals with water

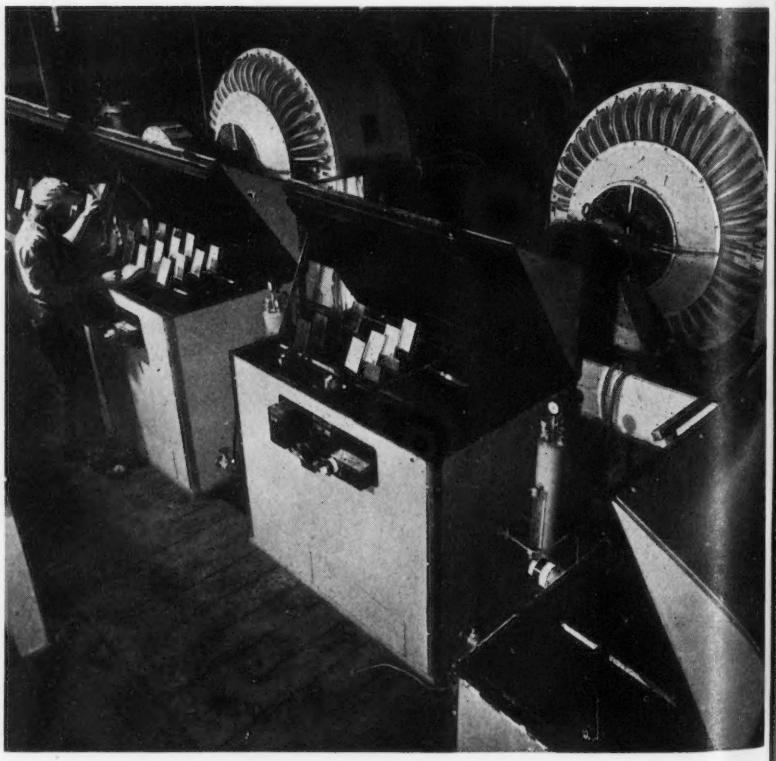
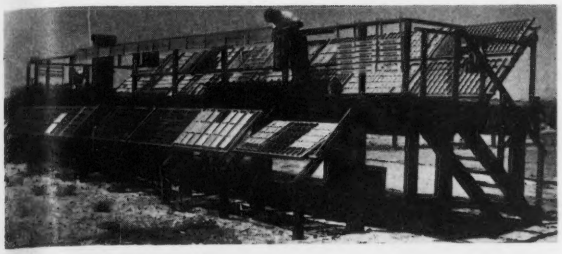


Figure 14—Salt spray cabinets.



Figures 15 and 16—Close-up of atmospheric salt spray tests, 80-foot site.

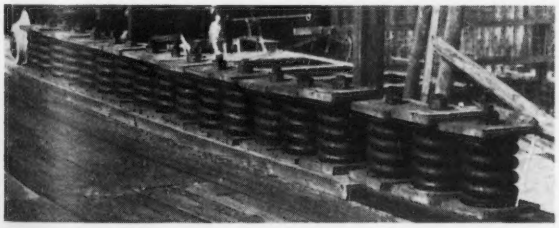


Figure 17—Ocean spray test of railroad car springs, 80-foot test site.

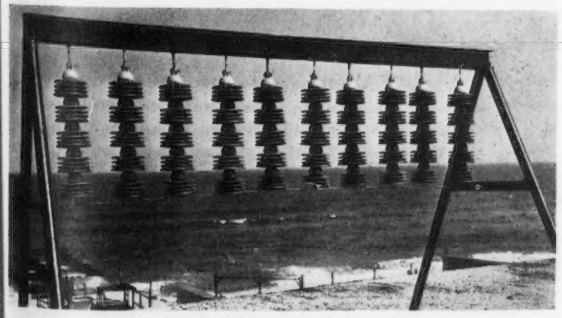


Figure 18—Close-up of insulator specimens on pump house roof.

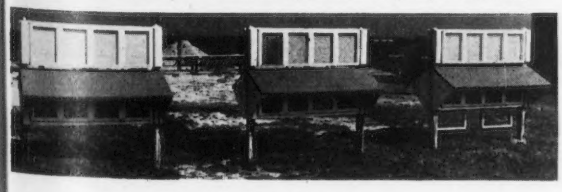


Figure 19—Insect screen test.

flowing at above velocity. It is now being used to develop polarization curves for various metals and alloys. The metal under test is the cathode, and a stainless steel anode is used. Progressive amounts of current are applied and the potential of the cathode to saturated calomel half cell is measured.

Another interesting project going on in the pump house is a study attempting to correlate results obtained in atmospheric exposure with results in four salt spray cabinets (see Figure 14). The four cabinets use sprays of 3% sodium chloride, 20% sodium chloride, synthetic sea water and actual sea water, respectively.

Very interesting comparative results are being developed at the two atmospheric test lots where over 20,000 individual specimens are exposed. The 800-foot lot shown in Figure 2 is subjected to a fairly clean marine atmosphere which is relatively free of actual salt spray, while the 80-foot lot (Figures 15 and 16) frequently is subjected to salt spray from the ocean. In many instances identical sets of specimens are installed at the two locations, and the results show the adverse effect of the salt spray in all cases where corrosion develops.

An outstanding example of this comparison is found in automobile steels with and without phosphate treatment with primer and with and without a final coat of enamel. The beneficial effect of the phosphate treatment is more pronounced at the 80-foot lot. Similarly, the advantage of low alloy steels over mild steel is more pronounced at the 80-foot lot. Corrosion is most severe where drying is delayed because of shade or other causes.

Tests at Kure Beach have shown that there is no advantage in applying a copper coating under nickel plating when making automobile bumpers. Nickel should be 0.002 inches thick if applied in one coat. However, if it is removed from plating bath and buffed between coatings, 0.001 inches is satisfactory. Economically, it is believed to be cheaper to apply 0.002 inches in one operation than to carry out the two-step operation.

Samples of titanium, zirconium, and Hastelloy C have shown no tendency to discolor or corrode at either location.

A number of pieces of equipment are on test. Note the railroad springs in Figure 17, the insulators in Figure 18, and the aluminum windows and screen material in Figure 19. The screen and window tests are set up facing south with eaves so that every type of exposure can be checked. The screen materials being tested are plastic, stainless steel, Monel, and galvanized steel. The plastics are standing up well. The stainless steel screens remain very bright. The Monel gives a small amount of green coloration, as does copper. The galvanized steel does not last too long.

There are many sea water and marine atmosphere corrosion problems of great economic significance. The cooperative program at Kure Beach is making progress in solving them.

Reference

1. Anon., Marine Corrosion Testing Station at Kure Beach, North Caroline, *Corrosion* **1**, 178-86 (1945) December.

A Method for Activating Stainless Steel Specimens Prior to Corrosion Tests*

By R. O. BAYER* and E. A. KACHIK*

EVERYONE WHO has run corrosion tests on the austenitic stainless steels has encountered conditions under which a specimen will corrode at a rapid rate during one or more periods of the test, but will corrode negligibly or not at all during the other periods. This behavior (which has been termed "borderline passivity") is apparently a manifestation of the activation-passivation phenomenon common to the austenitic stainless steels. Evidently these particular corrosive conditions are not actually passivating in nature, nor do they have sufficient activating (or depassivating) action to result in consistent break-down of a passive condition, once it is attained. Consequently corrosion proceeds normally when the specimen being tested is introduced into one of these "borderline" corrosive media while the surface is active, but does not occur if the specimen surface is in the passive condition.

In the use of laboratory tests as an indication of the suitability of stainless steels for some plant service, provision must be made for the possibility that the service may represent a borderline condition with respect to the development or maintenance of passivity. Common practice has been to expose as-ground or as-polished specimens to the testing solution and observe their performance. Frequently this procedure gives unsatisfactory results because of the variable performance of a group of specimens, some of which do not corrode, while others corrode rapidly, and, in most instances, do so for different proportions of the total exposure period. Apparently the as-ground specimens that do not corrode are passive when introduced into the test solution, while those that do corrode, are active when introduced.

An alternative procedure is to insure that all specimens are active when exposed to the testing solution, and then to observe whether they become passive during exposure and, if not, how severely they corrode. Results obtained with this latter procedure are more likely to be consistent than those obtained with the former. Results thus obtained also provide information on the passivating power of the testing solution as well as on the extent of the increased corrosion that may be expected if, and when, passivity is destroyed. The technique also is useful in studying how changes in alloy composition or changes in the testing solution affect the development of passivity. While stainless steels are used rarely in environments where they remain completely active, there is scientific as well as practical value in observations of their performance in that state.

A method for providing initial activation of the specimen in corrosion tests has been worked out and used in this laboratory with consistent success on stainless alloys under a wide variety of corrosive conditions. This method involves pickling the specimen immediately prior to its introduction into the corrosion-test medium. The following procedure is typical.

Four breakers are arranged in a series. The first beaker contains the hot pickling solution; the next three contain rinse solutions which are the same as that employed for the corrosion test. The solution in the latter three beakers is maintained at or near the temperature at which the corrosion test is to be carried out. The specimen for test, after proper preparation and weighing, is immersed in the pickling solution by means of a glass cradle. After a few seconds gas bubbles begin to form on the specimen and to evolve from its surface. After a controlled period of gas evolution, the specimen is transferred in succession from one to another of the three rinse solutions and, finally, into the corrosion-test flask or beaker which contains the corrosion-test solution. The successive transfers are effected as quickly as possible in order to minimize the time that the specimen is exposed to the air. At no time during the transfers is the specimen permitted to dry in the air after it is removed from the activation pickling solution. Sufficient time is permitted in the rinse solutions to be sure that all traces of the pickling solution are removed before the specimen is introduced into the corrosion-test solution.

Although almost any pickling solution that will actively corrode stainless steel can be used, a mixture of 12.7% nitric, 3.2% hydrofluoric, and 0.5% hydrochloric acids in percent by weight has been employed because of its uniform behavior and speed of reaction. The actual composition employed may vary within rather wide limits without detriment. Such a solution may be conveniently made up by adding 140 cc of 70% HNO_3, 60 cc of 48% HF, and 10 cc of 37% HCl to 790 cc of water. This pickling solution works best when heated within the range of 70 to 85° C.

Wide-mouth, 1000-cc erlenmeyer flasks and auxiliary equipment, as described in ASTM Specification A262-44T, are employed almost exclusively for the corrosion tests. One specimen is exposed in approximately 600 cc of test solution in a single flask. The solution is discarded and replaced after each period of test. Four specimens are pickled in a given 500-cc

★ Voluntarily submitted for publication April 26, 1949.
* Engineering Research Laboratory, Engineering Department, E. I. du Pont de Nemours & Co., Inc., Wilmington, Del.

lot of pickling solution. Each rinse beaker contains about 500 cc of the test solution. The pickling solution is made up just prior to use, although it is possible to make up a concentrated mixture of the three acids for subsequent dilution. Such a concentrated mixture must be stored in wax or HF-resistant plastic bottles.

Since the specimen cannot be weighed conveniently immediately after the activation-pickling treatment, there is no direct way to isolate the weight loss resulting from the pickling treatment from that resulting from the corrosion test. This weight loss, for the short pickling exposures of the order of 5 sec., is relatively small and may be ignored when the over-all weight loss in the corrosion test is large. In most cases, however, it is better to predetermine the magnitude of this weight loss and introduce this determination as a correction factor in the final result. In order to insure reproducible weight losses in the activation-pickling treatment, it is necessary to control the pickling-bath temperature to within 5° C and to control the pickling time. Exposure times of 5 to 15 sec. are satisfactory. It should be borne in mind, however, that pickling time starts only when active gas evolution begins from the specimen surface. Sometimes specimens will not begin to corrode in the pickling solution—as indicated by gas bubble evolution—for as long as 30 sec. after the sample is immersed. This initial immersion period usually has no effect on the actual weight loss occurring during the gas evolution period.

The data in Table I are typical of the results obtained in preliminary tests to determine the weight

TABLE I
Typical Weight Losses Due to Pickling Treatment[1]

ALLOY	WEIGHT LOSS, g.						Av. Wt. Loss, mg./sq. cm.[3]
	1st Period[2]	2nd Period	3rd Period	4th Period	5th Period	Average	
18-8-S	0.0090	0.0098	0.0105	0.0089	0.0092	0.0095	0.627
18-8-S-Mo (2.01% Mo)	0.0042	0.0036	0.0043	0.0034	0.0056	0.0042	0.230

[1] 12.7% HNO_3, 3.2% HF, 0.5% HCl at 80-85° C.
[2] 5-second periods.
[3] Specimens were approximately 2.5 cm. x 2.5 cm. x 0.6 cm.

TABLE II
Comparison of Corrosion Rates Obtained on Activated and Non-Activated Specimens of 18-8-S and 18-8-S-Mo in Boiling 1% H_2SO_4

ALLOY	Condition of Specimen	CORROSION RATE—In./Mo.					
		1st Period*	2nd Period	3rd Period	4th Period	5th Period	Average
18-8-S	Non-activated	0.10	0.0001	Nil	Nil	Nil	0.020†
18-8-S	Activated	0.085	0.092	0.12	0.088	0.075	0.0909
18-8-S-Mo	Non-activated	0.0015	Nil	0.0019	Nil	0.0039	0.0015†
18-8-S-Mo	Activated	0.0045	0.0055	0.0060	0.0060	0.0055	0.0055

* 48-hour periods.
† Shown for illustration only: normally periods that show no corrosion would not be averaged with periods showing high rates.

TABLE III
Comparison of Corrosion Rates Obtained on Activated and Non-Activated Specimens of 18-8-S and 18-8-S-Mo in Various Concentrations of Boiling Formic Acid

ALLOY	Condition of Specimen	Acid Concentration, Wt. %	CORROSION RATE—In./Mo.					
			1st Period*	2nd Period	3rd Period	4th Period	5th Period	Average
18-8-S	Non-activated	5	0.0027	Nil	Nil	Nil	Nil	0.0004†
18-8-S	Activated	5	0.0021	0.0025	0.0029	0.0039	0.0032	0.0029
18-8-S-Mo	Non-activated	5	0.0006	Nil	Nil	Nil	Nil	0.0001†
18-8-S-Mo	Activated	5	0.0007	0.0014	0.0019	0.0013	0.0014	0.0014
18-8-S	Non-activated	50	0.0088	Nil	Nil	Nil	Nil	0.0018†
18-8-S	Activated	50	0.0103	0.0105	0.0096	0.0082	0.0090	0.0095
18-8-S-Mo	Non-activated	50	0.0036	Nil	Nil	Nil	Nil	0.0007†
18-8-S-Mo	Activated	50	0.0022	0.0035	0.0032	0.0028	0.0029	0.0029
18-8-S	Non-activated	90	0.0072	Nil	Nil	Nil	Nil	0.0014†
18-8-S	Activated	90	0.0065	0.0060	0.0058	0.0062	0.0059	0.0061
18-8-S-Mo	Non-activated	90	0.0005	Nil	Nil	Nil	Nil	0.0001†
18-8-S-Mo	Activated	90	0.0003	0.0003	0.0006	0.0006	0.0004	0.0004

* 48-hour periods. † See Table II.

losses that result from the activation-pickling treatment. A high order of reproducibility is evident.

Table II compares results obtained on both 18-8-S and 18-8-S-Mo in boiling 1% H_2SO_4 with and without the preliminary activation procedure. It will be noted that the activated specimens were more consistent in their behavior than were the non-activated specimens. Some further illustrative data are given in Table III. These results were obtained from tests in boiling solutions of formic acid at the indicated concentrations.

This activation method has been employed for other than boiling solutions with equal success and for stainless alloys other than those of the 18-8 class. Satisfactory data have been obtained from tests at 80° C on the Ni-Cr-Cu-Mo stainless alloys employed for sulfuric acid service in concentrations of the acid ranging from 40 to 93%. For these more highly alloyed steels, it usually is necessary to increase the acid concentration of the pickling solution and the pickling time to about 15 sec. or more for consistent activation. This change in pickling conditions naturally requires a different correction factor.

It will be noted from the results given in Tables II and III that the corrosion rates obtained on activated specimens generally are higher than those obtained on non-activated specimens, even when measurable corrosion is obtained on the latter. It is believed these higher rates more nearly represent the inherent or true corrosion resistance of the particular alloy under the conditions of the test. Consequently in media which attack unpassivated stainless steel but do not corrode passivated steel, these results give a more realistic picture of what may occur in service when the passive condition is destroyed.

Acknowledgement

Thanks are due J. R. Auld, of this Laboratory, for the formic acid data.

Discussions

METHODS FOR PREVENTION OF RUST IN WATER TANKS—A preliminary Report*

By Fred Schumann, Electronic Consultants, Nashville, Tenn.

Discussion by

J. L. GILLILAND, JR.,
Chemical Engineer, Bureau of Reclamation, Denver, Col.

In presenting a very helpful summary of the problem of water tank protection, Mr. Schumann suggests that a combination of protective coating and cathodic protection seems to offer a happy compromise in that the two methods complement each other. Mr. Schumann then goes on to describe the "sentry action" of cathodic protection, whenever small pinholes develop in the coating.

There can be no doubt that there are many advantages to be gained by using cathodic protection in conjunction with a protective coating, but I question whether the thorough surface preparation and thick protective coating are necessary in this combination in waters which will plate out calcium carbonate. I propose that consideration be given to a coating applied as cheaply as possible. While the pinholes might be larger, and would form sooner, I would still expect the "sentry action" to occur, and the bare areas to be plated with calcium carbonate. Such a system would require a much smaller installation than if the cathodic unit alone were protecting the structure.

As far as I know, this idea has not been proved, but I see no reason why it should not be successful. Rather than considering the protective coating as the first line of defense, with the cathodic protection guarding against the formation of pinholes, I would like to consider the cathodic installation as the protective element, with some of its load being carried by a somewhat temporary insulating film.

While there may be many installations that can justify cathodic protection and a well-applied protective coating, there are many others that could justify cathodic protection if its use would permit the reduction of the costs involved in carefully cleaning the surface and in the application of an expensive coating

* CORROSION, 5, 198-200 (1949) June.
** Chemical Engineer, Bureau of Reclamation, Denver, Colorado.

A-TP12*

Sub-Committee T.P.-12—*Electrical Grounding Practices*

At the call of the chairman the above subcommittee met at the Mellon Institute of Industrial Research in Pittsburgh, Pennsylvania, on February 8, 1949. A list of the committee membership, indicating attendance at the meeting, is attached.

The committee was appointed to discuss corrosion problems arising from positive polarity grounding of d-c supply equipment and to make recommendations on the subject. The question arose because of a recent trend toward positive grounding of rectifiers supplying mine traction systems. In many quarters it was believed that this practice would lead to a difficult electrolysis problem on underground structures in the vicinity of the mines.

Following is a summary of the discussion along with the resulting recommendations:

It was developed that d-c street railway systems as well as interurban lines have been operated for many years with grounds on the negative side of the supply at substations. While there may be other reasons for this preference for negative grounding, it is believed that the controlling reason is the effect on electrolytic corrosion of the tracks and other metallic underground structures in their vicinity. In general, with the negative ground there occurs in the vicinity of the supply point a relatively confined area of intense depressed earth potential. Over the remainder of the traction system the potential of the tracks and the surrounding earth is raised. Under the condition of negative grounding there are several important advantages from the standpoint of electrolytic corrosion:

1. Metallic structures normally bonded to the negative bus, such as rails and the station grounding electrodes, are maintained negative to the surrounding earth and thus are not subject to electrolysis damage in the vicinity of the supply point where the current density is highest. Current is discharged to ground over the remainder of the track system, but because of the large area, the current density is small.
2. The structures of other utilities (pipes, cables, etc.) within the influence of the track potential are positive to earth and in danger of electrolysis damage within a small area near the supply point. Over the remainder of the system, within the influence of the tracks, these structures are generally negative to earth and pick up current which protects them against electrolysis.

In this circumstance it is possible to mitigate the problem in the vicinity of the supply point by means of bonds between the affected structures and the tracks or negative bus. Since the exposure area is relatively small these bonds are generally of practical length and cross-section.

If positive grounding at the supply point is used, the above advantages are not only lost but may become serious disadvantages. The tracks and ground structures at the supply point become positive where the current density is highest and thus are subject to rapid electrolysis damage. The structures of other utilities pick up current in the area close to the supply point and discharge it over the remainder of the system. While the current density in these discharge areas is smaller than before, the effect covers a much larger area and creates a problem on a more extensive section of plant. More important, the condition cannot be mitigated by a relatively simple bond to the tracks, as was the case with negative grounding. Bonds to the supply point ground are, of course, of no value because this point is now positive and bonds to it would increase the current delivery. Bonds might be made to the tracks at remote points where they are negative; however, the track potential at remote points is dependent on the load location, being negative only when a load is in the vicinity. While mitigation might be secured by means of a number of track bonds, suitably blocked against reverse current, the arrangement would be complex and costly. In the case of mine operations, it would be difficult to establish and maintain such an arrangement because the rails are not readily accessible to structures near the surface of the earth. Two other possible means of mitigation exist:

a. Drainage of current from the affected structures by means of a locally applied emf. It would probably be necessary to place insulating joints in the structures at proper points. This method is commonly called "cathodic protection" or "forced drainage." It is of value in the mitigation of soil corrosion but when used against stray currents becomes difficult and costly to apply.

b. Bonds from the affected structures to the negative trolley wire. This method would involve the use of dropping resistors in the bonding connection to limit the drainage current, and this current would be added to the load current. (This method was considered impractical by the committee for reasons of safety and economy.)

After the foregoing points were brought out in discussion, experience with grounding of mine traction systems was reviewed. In mines, "portable" substations are employed in order that the source of track supply may be moved from time to time to keep up with expanding operations. This requires that the substation equipment be compact so that it can be transported on mine cars. Rectifiers are commonly used. These are provided with heat exchangers connected to the rectifier tanks for cooling. The rectifier tank is the positive side of the circuit. Regarding rectifier substations, the following conditions exist, depending on whether positive or negative grounding is employed.

A. Negative Grounding

1. The rectifier tank is at positive trolley potential.
2. If the heat exchanger is metallically bonded to the rectifier tank through piping, it and its auxiliaries are at positive trolley potential.
3. In the compact design required in mine equipment there is the problem of insulating the heat exchanger from ground. Continuity of the piping to

* In this designation "A" stands for 1949 showing publication during that year.

the tank must be interrupted by insulating joints. The tank side of the joint is positive and exposed to electrolysis because of electrolytic conduction through the cooling fluid to ground via the body of the heat exchanger.

4. The above electrolysis damage can be mitigated by the use of expendable "targets" connected to the anodic sides of the insulating joints. The possible use of a non-electrical conducting coolant or the use of air cooled equipment was discussed.

B. Positive Grounding

1. The rectifier tank is at ground potential.
2. The heat exchanger may be bonded to the tank and grounded. Under this condition no electrolysis problem exists on the rectifier-heat exchanger parts.
3. There are some advantages from a safety standpoint because the heat exchanger piping and rectifier tank are maintained at ground potential.
4. There has been some experience with trolley insulator failures which has been attributed to positive grounding. Under certain soil conditions there appears to be a tendency for soluble ions to migrate across the damp insulator surfaces toward the negative conductor. This increases conductor leakage with attendant heating which softens the conductor supporting pin compound, permitting the trolley wire to fall. No similar experience has been noted with negative grounding.
5. There has been some experience with failure of negative feeder insulation possibly caused by electro-osmosis. No similar experience has been noted in mines with negative grounding.

The manufacturers' representatives stated that the rectifiers currently being manufactured are adaptable to either type of grounding at the option of the customer.

Regarding safety it was generally agreed that it need not be considered a factor in this problem since live parts may be adequately guarded.

It was generally agreed that there did not appear to be any tendency towards positive grounding of street railway and interurban systems. To do so would necessitate major rearrangements on existing systems, both in the traction system and on underground structures of other utilities. No problems have been encountered in insulating the rectifier tanks and other connected apparatus from ground.

It was agreed that a uniform grounding practice for mines is desirable. If neaghboring mines are operated with traction systems oppositely grounded, there is, under fault conditions, the possibility that almost double voltage could be applied across the insulators of the non-faulted system.

Recommendations

After considering all of the above factors at length the committee unanimously approved the following three recommendations:

1. Negative grounding of d-c traction power supply equipment, including rectifiers, is preferable from the standpoint of the stray current electrolysis problem on underground structures in the mine and on other structures in the vicinity, such as pipe lines, cables and the like.
2. New installations of d-c power supply equipment should be grounded on the negative side.
3. Every consideration should be given to converting existing positive grounded systems to the negative ground arrangement.

It was further unanimously agreed that a copy of the committee report along with the above recommendations should be transmitted to the Technical Practices Committee with the recommendation that copies be sent to the following interested organizations:

Intersociety Committee
American Mining Congress
Association of American Railroads
American Transit Association

Further, copies of this report are to be sent to the U. S. Bureau of Mines and the various state departments of mines, or their equivalent.

Respectfully submitted,

(signed) J. M. STANDRING
Secretary

National Association of Corrosion Engineers Members of the Electrical Grounding Practices Committee

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Dr. I. A. Denison, Chief, Underground Corrosion Section, National Bureau of Standards, Washington, D. C.

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Dr. G. H. Young, Assistant Director, Mellon Institute, Pittsburgh, Pa.

* Present at meeting of Feb. 8, 1949.
1. Guest.
2. Alternate for E. J. Gleim.
3. Alternate for H. Winograd.
4. Alternate for W. G. Thomas.

Topic of the Month

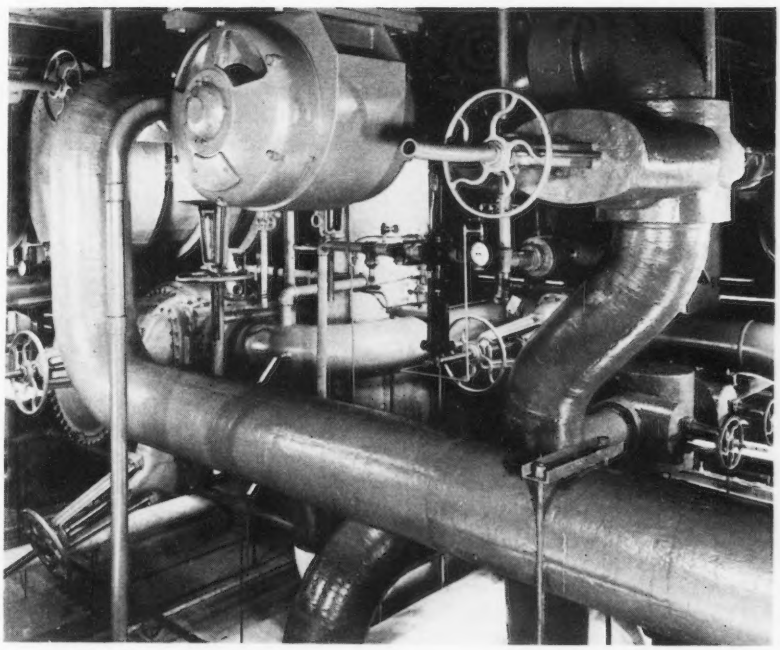
Multi-Layer Insulating Applications Include Non-Capillary Glass Fabric

Non-capillary glass fabric* which assures longer service life for multiple-layer pipe insulating coating because it does not tend to draw away the volatile compounds in mastic components was used in insulating coverings on both cold and hot lines at the Rochester, N.Y. Camera Works of Eastman Kodak Co.

The picture at right shows a portion of the compressor and pipe system included in air conditioning equipment installed at the Eastman plant. The "cold" lines presented a corrosion as well as a thermal problem in that it was desirable to bar vapor from the pipe surface and thus prevent condensation and deterioration.

The application consisted of, in order: 1) a troweled-on asphalt bitumen mastic coating; 2) an imbedded, spirally-wound fibrous glass fabric; 3) a glass fiber preformed pipe insulation; 4) troweled-on mastic; 5) imbedded glass fabric; 6) troweled-on bitumen mastic to a smooth finish; 7) brush coat of aluminum, lead and oil-based paint; 8) top coat of gray lead and oil-based paint.

The photograph at the left shows parallel steam lines erected outside the same plant. An insulating covering was applied to these lines wi th the view of retaining heat and protecting the pipe from the atmosphere and the insulation itself from loss of efficiency and deterioration through moisture penetration.



* Glasfab.

The covering in this case consisted of, in order: 1) preformed insulation; 2) troweled-on asphalt bitumen mastic; 3) spirally-wrapped and imbedded glass fabric; 4) troweled-on bitumen mastic to a smooth finish.

Efficiency and life of the insulation in both cases is dependent in large measure on the ability of the mastic to retain its volatile oils and thereby its flexibility. Because it is inorganic and non-capillary the glass material used has less tendency to draw oils away. It keeps its tensile strength under service conditions involving both low and high temperatures.

Cathodic Protection Notification Procedures

BULLETIN II PREPARED BY
CORRELATING COMMITTEE ON CATHODIC PROTECTION

JUNE, 1949

Bulletin I of this series, entitled "Management Information on Cathodic Protection of Buried Metallic Structures Against Corrosion," was issued in July, 1948 and published in *Corrosion*, 4, No. 9 (1948) Sept.

BULLETIN I prepared by this Committee informs management about the economic value of Cathodic Protection as a technique for combating underground corrosion of buried metallic plant. This corrosion and its contingent losses are costing American industry about a billion dollars per year.

Bulletin I describes in layman's language how such corrosion—which is a chemical attack of Nature—can be stopped by Cathodic Protection, which consists in impressing suitable external electric currents into the structures via metal masses called "anodes" buried in the soil nearby.

Bulletin I also describes the stray current problem arising out of Cathodic Protection, and the need for a "good neighbor policy" in dealing with it. Concerning these the bulletin states:

> "Some of the current introduced at the anodes to cathodically protect one structure may enter a neighboring structure and traverse it for a distance while enroute to the protected one. Where this current leaves the neighboring structure and enters the soil, corrosion occurs which is similar to street-railway stray-current electrolysis. It can be prevented in several ways, one of the commonest of which is to connect the neighboring structure to the protected one by a wire 'drainage bond' of proper resistance.
>
> "Because of this possibility of interaction, any operator planning a Cathodic Protection installation should notify operators of neighboring buried structures so that all concerned can appraise the interaction problems. Experience shows that these can be dealt with most effectively and satisfactorily through cooperative study and test by the engineers of the operators involved."

This Bulletin, No. II of the series to be issued, further indicates the desirability for such cooperation, and suggests procedures by which it can be fostered.

Advantages of Cooperation

An operator intending to install cathodic protection on his structure, or to change existing installations, will be well-advised to notify neighboring structure owners of his intention. This should be done while plans are being prepared. Such notification will initiate the cooperation needed not only to assure the operator of obtaining the protection sought for his own structure, but also to give his neighbors advance opportunity to consider possible stray-current corrosion or other undesirable effects on their structures. In addition, whenever a buried line or major extension is to be newly laid or removed, whether or not cathodic protection also is planned, the neighboring structure owners should be notified. This is because laying or removing the line may alter the electrical conditions on existing structures.

If the notification covers a proposed cathodic protection installation, each neighbor in turn will be equally well-advised to respond to the notification and, if deemed necessary, to cooperate in an engineering survey aimed to appraise the extent—if any—to which the proposed installation may effect his own structure. Also, if the survey indicates that any undesirable effect is probable, the neighbor should cooperate in the engineering of preventive measures.

The advantages to be gained from taking the above-described steps before commencing installation are mutual. The installing operator will benefit because he may learn, during the planning stage, what preventive measures he must allow for, and thus he can predicate his design on all pertinent facts. Also there is afforded an opportunity to determine neighboring structure conditions before they may be altered by the new installation. The neighbors will benefit because prompt response and cooperation enables suitable preventive measures to be taken at the time of the installation.

Form of Notification

Because of the wide variation in types of installation, it seems impractical to present any standard form of notification. However, to minimize later inquiry, each notification should include the following pertinent data:

1. If a buried line is to be laid or removed:
   a. Size and type of construction.
   b. Location or route (inclusion of map or sketch is desirable).
   c. Proposed dates of starting and completing construction or removal.
2. If a cathodic protection installation is proposed:
   a. Number and type of current supply units contemplated.
   b. Location of units (inclusion of map or diagram is desirable).
   c. Proposed dates of starting and completing installations.
   d. Designation of operator's representative to whom response should be directed, or who should be contacted in regard to joint survey and other engineering aspects.

Whom Should Be Notified

Presuming that the above-described cooperation is

sought—and that it will result from proper notification and prompt response—every operator intending to install cathodic protection, or a new line, or both, or to remove a line, should determine what other structures may be exposed or affected thereby.

Depending on local conditions, the proximity of a cathodic protection system can affect buried pipe lines, metal-sheathed cables, rail track systems and various other exposed metallic structures in contact with the soil. Transmission-tower footings and guy-wire anchors are involved occasionally. Cathodic installations also may affect the operation of railroad signal systems. While such currents are most likely to affect merely the exposed structures which cross or are close to the protected one, they may in some cases affect others more remote. Depending on conditions, their sphere of influence may be narrow or broad.

Extent of Interaction Between Structures

A full discussion of the factors determining the extent of interaction between a cathodically-protected structure and an exposed one is too technical for this bulletin. However, three factors especially deserve mention herein and careful consideration by all concerned, to wit:

1. *"Influence" of Protective Installation:* The tendency of the protective currents to stray to and influence neighboring exposed structures can be minimized (1) by judiciously locating the anodes; (2) by using additional and well-separated anodes if necessary to reasonably distribute the protective current and thus limit the amount introduced into the earth at any single location; and (3) by insulating or coating the protected structure so that the required protective currents—and hence the possible stray currents—are kept to a minimum.
2. *"Coupling" Between Structures:* Coupling depends on (1) earth resistivity and (2) structure separation. The higher the earth resistivity (resistance per unit cube), the greater is the area over which the protective currents will migrate. The greater the separation between the protected and exposed structures in the earth, the less is the interaction between them.
3. *"Susceptiveness" of Exposed Structure:* Exposed structures which are insulated by coatings, and those of poor electrical conductivity, are less likely to be affected by stray currents than are bare structures and those of high conductivity. Well-insulated structures present a minimum exposure to stray currents. However, coating insulation can deteriorate in service, in which event its protective value is correspondingly reduced.

From the foregoing it appears that the factor of "influence" is substantially under the control of the designer of the protective system. Thus, in designing the system, he should use the best techniques consistent with over-all economy. "Coupling" depends also on soil resistivity that cannot be controlled, but it can be minimized to the extent that by advance planning operators may be able to avoid the close association of their structures.

Susceptiveness is under the control of every operator on his own new structures, whether or not cathodic protection is used. Cathodic Protection is becoming widely recognized and applied as a practicable means of reducing corrosion of buried structures. Thus over-all benefits will accrue if every operator will design and install his new plant so as to keep its susceptiveness as low as possible. This may involve, e.g., use of coatings or of insulated joints. By minimizing exposure of the new line to stray-current corrosion, the operator also will minimize its exposure to natural corrosion.

Sources of Data on Structure Locations and Owners

The act of proper notification obviously requires the installing operator to know also which neighbors own the other structures that may be involved. The notices preferably should be directed to operating officials presumed to have jurisdiction in such matters. In urban areas where structures are relatively short and the neighbors are usually well-known, this information should be readily obtaintable. Where urban "joint electrolysis committees" exist,* such information usually can be obtained from their chairmen or secretaries. But an operator who intends to install or protect a long line traversing many miles of varied country may have greater difficulty in determining whom to notify.

To assist in this matter, certain generally-available sources of data on structure locations, ownerships, operating personnel, et cetera are called to attention herein.**

Railroads: Several types of maps are available to show the routes of railroads. A four-sheet general map to scale 1/2,500,000 is the "Railroad Map of the United States."[1] Handy identity and distance maps in atlas form are available in two forms.[2-3] The best exact route alignment data generally available at nominal cost are in the maps of the U. S. Geological Survey. These include a series of state maps to scale (most of them) of 1/1,000,000;[4a] another state map series to scale (most of them) of 1/250,000;[4b] and the many regular topographic quadrangles varying in scale from 1/62,500 to 1/24,000.[4c] Lists of rail carriers, with business addresses and names of key personnel appear in The Pocket List of Railway Officials.[5]

Electric Railways: A list of headquarter cities of electrified rail carriers, with names of carriers, and their business addresses, key personnel and system data, appears in Mass Transportation Directory.[6] Most of the carriers issue handy maps of their systems.

Petroleum Pipe Lines: Industry-fostered maps to scale 1 inch = 24 miles showing all crude oil and products trunk pipe lines in (a) Central United States or (b) Eastern United States can be purchased at nominal cost.[7] These maps indicate the names of the line operators. Maps of such lines in California can be obtained as of May 1949 only from private sources.

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* An available list of "joint electrolysis committees" is given in Appendix A.

** Publishers of the source materials are listed in Appendix B, 1. etc. . . . refers to list in Appendix B.

Lists of most oil pipe line carriers, with business addresses and names of key personnel, appear (among other places) in the Petroleum Register[8] and the Directory of Pipe Line Personnel.[9]

For the oil-producing country, where innumerable oil gathering and field service pipe lines exist, composite line maps are not usually available. However, local field maps showing the individual oil properties or "leases," and names of their operators or "producers," usually can be purchased from various sources. Field line maps of oil and gas producers, and gathering maps of the various pipe line carriers, usually can be inspected at the producers' and carriers' district, division and head offices.

Gas Pipe Lines: A general map can be purchased titled "Principal Natural Gas Pipe Lines of the United States"[10] Data on location of local gas distribution lines may be obtained at the utilities' local business offices. A list of gas companies, with business addresses, names of key personnel and considerable system data appear in Brown's Directory of American Gas Companies.[11]

Water Pipe Lines: Most water pipe lines are confined to urban areas, although there are also suburban companies, and some of the larger urban systems are served by feeder lines from outlying reservoirs, et cetera. Data on locations of water lines may be obtained at the operators' local business offices, or, if municipally-owned systems, from the City Engineers' or Public Works Administrators' offices. Lists of the City Engineers, Water Works Superintendents (where systems are municipally-owned), Street Superintendents and Superintendents of Sewerage for the 1072 cities having more than 10,000 population are listed in The Municipal Index and Atlas.[12] Another source of water system personnel information is the membership list of American Water Works Association.

Central Steam Heating and Refrigeration Pipe Lines: Pipe lines of companies furnishing these services are confined to a relatively few urban areas. Data on locations of these lines may be obtained at the operators' local business offices.

Electric Power Cables and Transmission Lines: Data on location of electric power cables, which generally are confined to urban areas, may be obtained at the utilities' local offices. General maps of principal suburban, interurban and interstate transmission lines appear in atlas of Principal Electric Facilities of the United States.[13] Lists of cities and towns, with names of the electric utilities in each, and their business addresses and officials, appear in the Central Station Directory.[14]

Communications Cable—Bell System: These cables may extend interstate and interurban as well as in urban areas. They are classified as "underground" if in ducts, and as "buried" if plowed or trenched in. Data on their locations may be obtained from the District or Division Plant Superintendents of the Bell System company operating in the area involved. Lists of the cities and towns served by each of these companies, their operating areas, and the business addresses and key personnel of their head offices (and in some cases of their area offices), appear in Telephony's Directory.[15] It is proper to notify the above referred-to superintendents concerning involvement of local and intra-state cables. In cases involving interstate cables, the District Plant Superintendents of the Long Lines Department of the American Telephone and Telegraph Company should be notified. Their headquarters offices are listed in Appendix C.

Communications Cables—Independent Telephone Companies: These cables, underground or buried, may extend interurban as well as in urban areas. Data on their locations may be obtained from the offices of the companies. Lists of the cities and towns served by independent companies, with company names, business addresses and key personnel, appear in Telephony's Directory.[15]

Communications Cables—Western Union: Underground and buried cables of Western Union Telegraph Company are confined principally to urban areas. Data on their location may be obtained from the Company's local Plant and Engineering Department. Notification should be addressed to Area Superintendent—Plant & Engineering. Their headquarters offices are listed in Appendix D.

Municipal Signal Systems: Underground and buried municipal signal cables are confined to urban areas. Data concerning their location may be obtained from local offices of fire and police authorities. Lists of the Fire Chiefs and Police Chiefs of cities with more than 10,000 population appear in the Municipal Index & Atlas[12] and in The Municipal Year Book.[16] A source of the names of the signal system superintendents is the membership list of International Municipal Signal Association.

Joint Industry Committees

Reference has been made to the existence in many urban areas of "joint electrolysis committees" through which the problems of notification and joint survey in corrosion mitigation are being handled with a minimum of effort and a maximum of cooperation. These committees usually are composed of representatives from each operator of buried structures in the area. The success which has attended their work indicates their value.

It would seem that the voluntary formation of somewhat similar committees can assist in the correlation of cathodic protection notification and survey problems in other urban areas and in non-urban areas, these latter appropriately sized according to community of interests. In some non-urban areas there may be so many operators that it will be impractical for all of them to have individual representation on the committees. In such areas the committees perhaps can more practically be composed of one or two representatives informally selected by the interested operators in each concerned industry.

thus giving the committees a composition similar to that of the Correlating Committe on Cathodic Protection.

APPENDIX A

Joint Electrolysis Committees

ELECTROLYSIS SURVEY COMMITTEE OF BALTIMORE CITY
Chm: Mr. Hugh H. Hunter
Public Service Commission
Baltimore 2, Maryland

CHICAGO JOINT ELECTROLYSIS COMMITTEE OF VARIOUS UTILITY COMPANIES
Chm: Mr. L. F. Greve
Commonwealth Edison Company
Chicago 90, Illinois

CINCINNATI COMMITTEE ON ELECTROLYSIS
c/o: Mr. Edgar Dow Gilman
City Hall (Temporarily
Cincinnati, Ohio Inactive)

CLEVELAND COMMITTEE ON ELECTROLYSIS
Chm: Mr. G. R. Canning
Ohio Bell Telephone Company
750 Huron Road
Cleveland 15, Ohio

DENVER COMMITTEE ON ELECTROLYSIS
Chm: Mr. A. M. Spaulding
Mountain States Tel. & Tel. Co.
Denver, Colorado

DES MOINES ELECTROLYSIS COMMITTEE
Chm: Mr. Earl Olmsted
Des Moines Gas Company
Des Moines, Iowa

DETROIT COMMITTEE ON ELECTROLYSIS
Chm: Mr. R. M. Lawall
American Tel. & Tel. Co.
1814 Book Tower
Detroit 26, Michigan

JOINT COMMITTEE FOR THE PROTECTION OF UNDERGROUND STRUCTURES IN THE EASTBAY CITIES
Chm: Mr. M. N. Clark
Pacific Gas & Electric Co.
1625 Clay Street
Oakland 12, California

LOUISVILLE ELECTROLYSIS COMMITTEE
Chm: Mr. S. H. Gates
Southern Bell Tel. & Tel. Co.
P. O. Box 538
Louisville, Kentucky

MILWAUKEE ELECTROLYSIS COMMITTEE
Chm: Mr. Glenn Chamberlain
Milwaukee Gas Light Co.
Milwaukee, Wisconsin

NEW HAVEN ELECTROLYSIS COMMITTEE
Chm: Mr. E. A. Johnson
Southern New England Tel. Co.
227 Church Street
New Haven 6, Connecticut

GREATER NEW YORK ELECTROLYSIS COMMITTEE
Chm: Mr. Sumner Hayward
New York Telephone Co.
101 Willoughby Street
Brooklyn 1, New York

OMAHA-COUNCIL BLUFFS ELECTROLYSIS COMMITTEE
Chm: Mr. J. C. Detweiler
Metropolitan Utilities District
Utilities Building
Omaha, Nebraska

SUBURBAN PHILADELPHIA ELECTROLYSIS COMMITTEE
Chm: Mr. A. V. Smith
370 Trevor Lane
Bala-Cynwyd, Pennsylvania

PITTSBURGH CORROSION COMMITTEE
Chm: Mr. C. A. Erickson
Peoples Natural Gas Co.
545 William Penn Way
Pittsburgh, Pennsylvania

ROANOKE ELECTROLYSIS COMMITTEE
c/o: Mr. C. M. Baldock
Chesapeake & Potomac Tel. Co.
Roanoke, Virginia

SACRAMENTO UNDERGROUND JOINT COMMITTEE
Chm: Mr. C. M. Hoskinson
112 City Hall
Sacramento, California

SAN FRANCISCO AREA JOINT COMMITTEE
Act'g. Chm: Mr. L. M. Perrin
Hetch Hetchy Water Supply
San Francisco, California
(Now Being Organized)

ELECTROLYSIS COMMITTEE OF SOUTHERN CALIFORNIA
Chm: Mr. I. C. Dietze
Department of Water & Power
Box 3669 Terminal Annex
Los Angeles 54, California

WHEELING COORDINATING COMMITTEE ON CORROSION
c/o: Mr. C. F. Aulick, Jr.
C. & P. Telephone Co. of W. Va.
Wheeling, West Virginia
(Temporarily Inactive)

YOUNGSTOWN COMMITTEE ON CORROSION CONTROL
Chm: Mr. F. W. Nimer
Ohio Edison Company
Akron, Ohio

APPENDIX B

Publishers of Maps and Directories

1. Railroad Map of the United States (annual)
Commanding Officer, Army Map Service, 6500 Brooks Lane, Washington 16, D. C.
2. Handy Railroad Atlas of the United States (annual)
Rand McNally & Co., 536 S. Clark St., Chicago, Illinois.
3. Leahy's Hotel Guide & Travel Atlas (annual)
American Hotel Register Co., 226 W. Ontario St., Chicago 10, Illinois.
4. (a) State Index Maps—without red overprints, scale 1/1,000,000 (5 cents each).
(b) State Maps to 4 x scale of Index Maps, scale 1/250,000 (25 cents each).
(c) U. S. Topographic Quadrangles, various scales (10 cents each).
The Director, U. S. Geological Survey, Washington 25, D. C.
5. The Pocket List of Railway Officials (quarterly)
Railway Equipment & Publishing Co., 424 W. 55th St., New York, N. Y.
6. Mass Transportation Directory (annual)
Kenfield-Davis Publishing Co., 608 S. Dearborn St., Chicago 5, Illinois.
7. Maps of "Petroleum Pipe Lines in" (a) "Central United States" or (b) "Eastern United States" (kept up-to-date)
L. L. Ridgway Co., 615 Caroline St., Houston, Texas.
8. Petroleum Register (annual)
Mona Palmer, 794 Stanford Ave., Los Angeles 21, California.
9. Directory of Pipe Line Personnel
Midwest Oil Register, P. O. Box 892, Tulsa, Oklahoma.
10. Map of "Principal Natural Gas Pipe Lines of the United States"
Federal Power Commission, Washington, D. C.
11. Brown's Directory of American Gas Companies (annual)
Moore Publishing Co., 9 East 38th St., New York, N. Y.
12. The Municipal Index & Atlas (annual)
American City Magazine Corp., 470 Fourth Ave., New York 16, N. Y.
13. (a) Maps of "Principal Electric Facilities in the United States" (complete coverage in atlas form)
(b) Maps of "Principal Electric Utility Generating Station and Transmission Lines." Separate maps for 11 regions and 6 congested areas)
Federal Power Commission, Washington, D. C.
14. Central Station Directory (annual)
McGraw-Hill Publishing Co., Inc., 330 W. 42nd St., New York, N. Y.
15. Telephony's Directory (annual)
Telephony Publishing Corp., 608 S. Dearborn St., Chicago, Ill.
16. The Municipal Year Book (annual)
The International City Managers' Association, 1313 E. 60th St., Chicago, Ill.

APPENDIX C

Location of District Offices of The American Telephone and Telegraph Company Long Lines Department

Birmingham 3, Alabama, Room 703, Comer Building
Denver 2, Colorado, 931 14th Street, Room 404
West Haven 16, Connecticut, P. O. Box 31
Jacksonville 2, Florida, Room 1130, Lynch Building
Atlanta 3, Georgia, Room 909, 51 Ivy Street
Joliet, Illinois, 7 East Clinton Street
Springfield, Illinois, 422 South 5th Street
Indianapolis 4, Indiana, Room 602, 240 North Meridian Street
Boston 9, Massachusetts, Room 505, 125 Milk Street
Detroit 26, Michigan, 1814 Book Tower
Minneapolis 2, Minnesota, 420 3rd Avenue
Kansas City 6, Missouri, 1426 Locust Street
St. Louis 3, Missouri, 2651 Olive Street
Omaha 2, Nebraska, 723 Service Life Building, 1904 Farnum Street
Newark 2, New Jersey, Room 1106 Nat. Newark Building, 744 Broad Street
Alburquerque, New Mexico, 300 West Copper Avenue
Albany 1, New York, Room 803B, 158 State Street
Buffalo 2, New York, 51 Erie Street
Charlotte, North Carolina, Room 308, 208 North Caldwell Street
Cincinnati 2, Ohio, Room 810, 209 West 7th Street
Cleveland 15, Ohio, Room 531, 750 Huron Road
Harrisburg, Pennsylvania, 124 Pine Street
Philadelphia 6, Pennsylvania, 648 Bourse Building
Pittsburgh 19, Pennsylvania, 416 7th Avenue
Nashville 3, Tennessee, 1113 Nashville Trust Building
Dallas 4, Texas, 4100 Bryan Street
Richmond 19, Virginia, Room 1120, Central National Bank Building
Washington, D. C., 1809 G Street, N. W.

APPENDIX D

Location of Area Offices of The Western Union Telegraph Company

(Notify: Area Superintendent—Plant & Engineering)
Los Angeles 14, California, 745 South Flower Street
Oakland 12, California, 125 Twelfth Street
Atlanta 3, Georgia, 56 Marietta Street
Chicago 5, Illinois, 427 South La Salle Street
New Orleans 12, Louisiana, Carondolet & Perdido Street
Boston 10, Massachusetts, 230 Congress Street
Detroit 26, Michigan, 536 Shelby Street
Minneapolis 1, Minnesota, 317 Second Avenue, South
Kansas City 6, Missouri, 114 East Seventh Street
St. Louis 1, Missouri, 910 Chestnut Street
New York 13, New York, 60 Hudson Street
Syracuse 2, New York, 351 South Warren Street
Cincinnati 2, Ohio, 216 Dixie South Terminal Building
Portland 5, Oregon, 239 South West Broadway
Philadelphia 7, Pennsylvania, 230 South Eleventh Street
Dallas 1, Texas, 2028 Main Street

CORRELATING COMMITTEE ON CATHODIC PROTECTION

Chairman: H. H. Anderson, American Petroleum Institute
Secretary: F. E. Dolson, Jr., American Water Works Association

AMERICAN GAS ASSOCIATION
Guy Corfield, Southern California Gas Company, Los Angeles, California
F. J. McElhatton, Panhandle Eastern Pipe Line Company, Kansas City, Mo.

AMERICAN PETROLEUM INSTITUTE
H. H. Anderson, Shell Pipe Line Corporation, Houston, Texas
L. F. Scherer, The Texas Pipe Line Company, Houston, Texas

AMERICAN PUBLIC WORKS ASSOCIATION
Robert J. Kuhn, Consulting Engineer, New Orleans, Louisiana
W. R. LaDue, Bureau of Water and Sewerage, Akron, Ohio

AMERICAN WATER WORKS ASSOCIATION
F. E. Dolson, Jr., St. Louis County Water Company, St. Louis, Missouri
A. R. Davis, City Water Department, Austin, Texas

ASSOCIATION OF AMERICAN RAILROADS
R. B. Amsden, Illinois Central Railroad, Chicago, Illinois
A. E. Archambault, New York Central Railroad, New York, N. Y.

BELL SYSTEM
*K. L. Maurer, Bell Telephone Laboratories, New York, N. Y.
J. M. Standring, American Telephone & Telegraph Company, New York, N. Y.

EDISON ELECTRIC INSTITUTE
J. J. Pokorny, Cleveland Electric Illuminating Company, Cleveland, Ohio
M. W. Ghen, Duquesne Light Company, Pittsburgh, Pa.
(Alternate: C. K. Poarch, Edison Electric Institute, New York, N. Y.)

INTERNATIONAL MUNICIPAL SIGNAL ASSOCIATION, INC.
John D. Southwell, Supt. of Fire and Police Communications, Beaumont, Texas
Frank Smith, Supt. of Fire Alarm, Tulsa, Oklahoma

NATIONAL ASSOCIATION OF CORROSION ENGINEERS
M. C. Miller, Ebasco Services, Inc., New York, N. Y.
O. C. Mudd, Shell Pipe Line Corporation, Houston, Texas

UNITED STATES INDEPENDENT TELEPHONE ASSOCIATION
G. W. Miller, Rochester Telephone Corporation, Rochester, N. Y.
G. C. Richert, U. S. Independent Telephone Assn., Washington, D. C.

WESTERN UNION TELEGRAPH COMPANY
L. S. Terrell, Western Union Telegraph Company, Atlanta, Georgia
E. A. Cooke, Western Union Telegraph Company, New York, N. Y.

* Deceased.

Joint Cathodic Protection Systems

BULLETIN IV PREPARED BY
CORRELATING COMMITTEE ON CATHODIC PROTECTION

MAY, 1949

Bulletin I of this series, entitled "Management Information on Cathodic Protection of Buried Metallic Structures Against Corrosion," was issued in July, 1948 and published in *Corrosion*, 4, No. 9 (1948) Sept.

1. Nature of Problem and Purpose of Bulletin

Bulletin I prepared by this committee informs management about the economic value of Cathodic Protection for combating underground corrosion of buried metallic plant. This corrosion and its contingent losses are costing American industry about a billion dollars per year.

Bulletin I describes in layman's language how such corrosion—which is a chemical attack of Nature—can be stopped by Cathodic Protection, which consists in impressing suitable external electric currents into the structures via metal masses called "anodes" buried in the soil nearby.

The bulletin points out that such external currents, beneficially impressed for the protection of one structure, can stray through the soil and cause corrosion or other undesirable effects on neighboring structures. Further, that these adverse effects can be prevented, e.g., by connecting the neighboring structures to the protected one with wire bonds of proper resistance. Thus the bulletin stresses the need for cooperation among the structure owners so that these preventive measures can be properly engineered and applied.

Bulletin I also points out that where neighboring structures of two or more operators are subject to similar natural corrosion damage, "joint cathodic protection systems" can be designed, installed and operated economically to the benefit and satisfaction of all concerned.

This Bulletin, No. IV of the series to be issued, gives further information about these joint systems. It discusses the techniques of their design and installation, and possible divisions of responsibility for their construction, operation and maintenance; and the sharing of costs. Also, it presents an outline of the principal points that may be included in any agreement between the structure owners.

2. The Case for Joint Cathodic Protection

The idea of joint Cathodic Protection is not unique. It follows the economically sound principles of the joint solution of local corrosion problems so well developed during the last three decades in metropolitan areas by "joint electrolysis committees."

The economy of joint Cathodic Protection on neighboring structures is evident. Let us assume that Operator A owns a line which traverses an area of corrosive soil, and that—aware of this fact—he decides to install Cathodic Protection on his line. Assume also that Operator B owns a neighboring line that is similarly threatened by natural corrosion, but that he has no such preventive measures in mind.

Suppose that A proceeds alone to protect his line. In this event, his impressed protective currents then may migrate into B's line and cause electrolytic corrosion at the points whence they leave to return into A's line. Sometimes this can be corrected by a change in the design of A's installation. Otherwise such correction may require, for example, bonding the two lines together with a wire of proper resistance. The installation of such a bond and the resultant use of additional current will increase A's costs without providing to B's line any substantial protection against natural corrosion.

Suppose that B, now also concerned about natural corrosion, decides to install Cathodic Protection independently on his line. His impressed currents in turn may adversely affect A's line unless other or different bonds are installed. Thus, where each party attempts an individual solution, installation costs and operating costs for both are increased. This causes economic waste.

Such a situation calls for joint Cathodic Protection at the outset. If A and B will jointly engineer, install and operate such a system, both lines can be even more effectively protected. Furthermore, this can be accomplished with total capital and operating costs substantially less than the total costs of two individual systems, even if these were installed without regard to their mutual interference. By equitably sharing the joint costs, A and B both can enjoy maximum protection at minimum cost. This insures maximum economic gain.

While this Bulletin IV does not treat cases where the protection of one structure affects conditions on a neighboring structure not requiring similar protection, such cases also are best dealt with by full cooperation and mutual appreciation of the problem. The need for these attitudes was made clear in Bulletin I.

This bulletin will perhaps find its widest application in open country where the neighboring structures involved are continuous and cross infrequently. However, the same cooperative approach is even more desirable in developed areas having more complex structure layouts which create more difficult technical problems.

3. Fundamentals of Joint System Design

The design of a joint Cathodic Protection system, including each sub-installation, should aim to give effective protection. Also, it should aim to do this as cheaply in capital and operating costs as is practicable considering all structures or lines involved. To accomplish this, several fundamentals should be kept in mind:

a. The engineer of each participating structure-owner should be the sole judge of his structure's own protection requirements.
b. Joint tests should be made to determine how much protective current each structure requires, taking into account the mutual reactions of all structures to such currents.
c. The wire bonding and anode system should be of ample size to handle the total current to all structures.
d. The total current should be divided among the structures in proportion to their needs.

Each of these design fundamentals is discussed briefly below.

A. *Judging Requirements*

Different voltage and current conditions are required for proper protection of different types of structures; e.g., as between steel pipes and lead cables, between coated and uncoated pipes, between cables in ducts and buried cables, etc. Also, the techniques of testing for and prescribing such requirements are still being developed. Thus, different engineers may use different protection criteria. Joint studies and tests can proceed best when each participant's engineer is free to state and use his own criteria.

B. *Joint Tests*

Different engineers will in many cases wish to use different testing techniques and instruments. However, because the changes in potentials of and currents in the various structures are interdependent, any tests made by individual participants must be coordinated into a joint result. This usually can be effected informally by the engineers.

C. *Over-all Design*

The coordinated result of the joint tests will indicate how much current should flow to each structure, and the effective resistance presented by each to such current. After the individual requirements are known, the total protective current demand can be found. Then, based on test data, the anode structure can be designed. The operating voltage of the rectifier or generator must be ample to impress the total protective current through the resistance of the entire electrical network. In most cases both the current and voltage outputs of the rectifier or generator should have some margin for contingencies.

D. *Dividing Current Among Structures*

The total current can be distributed by adjusting the resistances of the leads from the rectifier or generator to the several structures. These resistances can be estimated from the initial test data, but because of environment changes after the installation has been in operation for some time, subsequent adjustments usually must be made. Tests are desirable from time to time to ascertain that all needed protection is afforded.

When further studies of the techniques of Cathodic Protection are made and reported on, and as more experience is gained with joint installations, the prevalent variations in testing technique and protection criteria should be reconciled, thus simplifying cooperative design.

4. Division of responsibility and Costs

With joint protection installations it has proven most practical for one participant to own and maintain the rectifier or generator, the anode structure and all other equipment common to all protected structures. Conversely, each participant preferably should own and maintain the wires, connections, etc., serving only its own structure.

The participant which can most readily and efficiently do the job should normally build, own and maintain the common parts of the installation. However, a fair division of the common initial, fixed, maintenance and power costs must be worked out among all participants. Although conditions will vary widely, in each case such fair division among them can be determined by analysis of the equities.

The agreed arrangement for division of costs should be flexible enough to accommodate later desirable changes in total protective current or current distribution. In some cases such flexibility has been promoted by agreement of the participants to share the annual costs equally rather than to recompute such costs with each minor change in plant or current use. In other cases the participants have agreed to share such costs on the basis of distribution of current flow. For clarity, those two arrangements are recited more concisely; viz:

a. The sum of the annual (actual or estimated) fixed maintenance and power costs of the joint installation will be divided equally among the participants.
b. The sum of the annual (actual or estimated) fixed, maintenance and power costs of the joint installation will be divided among the participants in proportion to the protective current flowing to each structure.

A compromise between these two arrangements is a third possibility for division of costs.

5. Agreements Between Participants

Before the testing and the installation work is begun, the participants should agree on the responsibilities of each. Generally such an agreement is reached informally on the basis that each should do his fair share. To confirm the arrangement for division of annual costs, some more formal agreement is advisable. In many cases this can be handled by an interchange of letters or by jointly prepared memoranda recording the result of conferences.

If a general agreement seems desirable, it may include any or all of the following provisions:

1. If either party contemplates installation of cathodic protection equipment on its underground structures in any area in which the other party also owns underground structures, it should invite the other party to join in a cooperative study of the common problem.

2. If such a study is agreed upon, both parties should cooperate in the conduct of necessary surveys, and the preparation of plans and estimates, and then decide whether or not to install and operate joint cathodic protection facilities for their common benefit.

3. If it is decided to install and operate such facilities, the parties should agree as to which of them shall build, own, operate, and maintain the proposed joint installation. (In general this should be the one which, under the circumstances, can perform the services at the lowest cost.) The parties should agree

also on an equitable division of the annual costs—including fixed charges and operation and maintenance expenses—of operating such installation, taking into consideration estimates of annual costs, results of field tests and any other pertinent matters.

4. The party to make the joint installation should then do so in accordance with the jointly approved plan. When the installation is completed, field tests and adjustments should be made to the mutual satisfaction of both parties.

5. An arrangement should be made for billing the costs of operation at suitable intervals.

6. A record of each joint installation should be made a part of the agreement. Appendix A indicates the data pertinent to such a record.

(Names of members of Correlating Committee on Cathodic Protection may be found on Page 6 preceding).

APPENDIX A
Record of Joint Cathodic Protection Installation

Description and location of installation:_____

_____

Installed and Owned by:

_____

Agreed annual costs of installation effective from_____

_____ are as follows:

Fixed charges (____% of total capitalized cost of $_____) $_____

Fuel or electric energy costs - _____

Other Operation and Maintenance costs - - - - - - - _____

Total agreed Annual Costs $_____

Total Annual Costs are to be divided as follows:

_____ Company ___% $_____

_____ Company ___% _____

TOTAL - - - $_____

BULLETIN I

Correlating Committee on Cathodic Protection

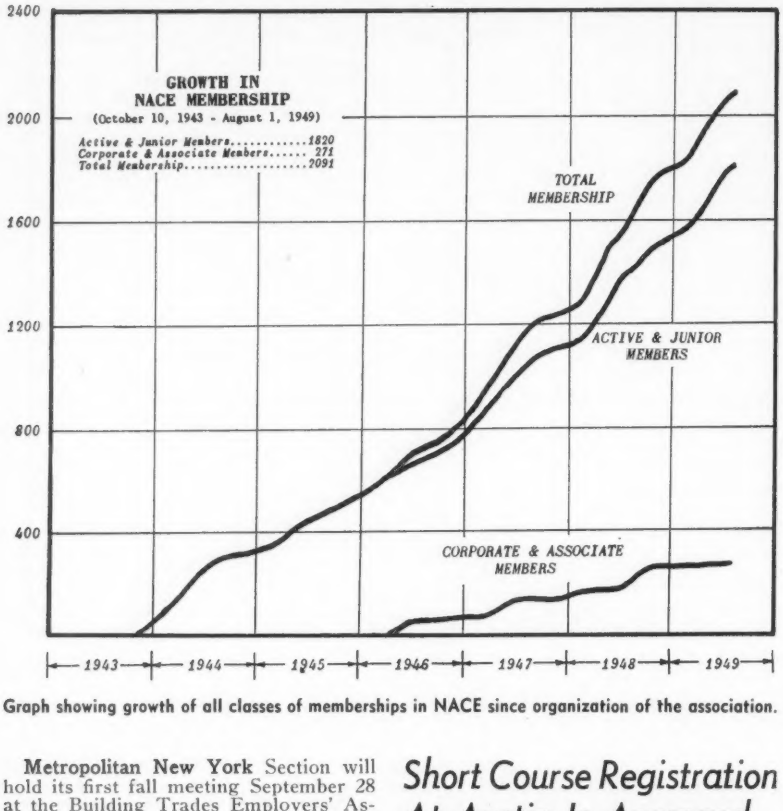
"MANAGEMENT INFORMATION ON CATHODIC PROTECTION OF BURIED METALLIC STRUCTURES AGAINST CORROSION"

IS AVAILABLE IN REPRINT FORM FROM CENTRAL OFFICE, NACE, 919 MILAM BUILDING, HOUSTON, TEXAS

In Lots of 10 or more, each.....10c

NACE News

NACE Membership Increases 30 Percent



Graph showing growth of all classes of memberships in NACE since organization of the association.

A 30 percent overall increase in membership which includes a 53 percent increase in corporate and associate members was registered by The National Association of Corrosion Engineers in the period January 1-August 1, 1949, records at Central Office NACE show. Total membership increased from 1600 to 2091 and there has been a net increase of 94 corporate and associate members.

Over 855 separate companies and universities are represented by NACE members. This wide variety of interest is distributed over 43 states and in 40 foreign countries.

Since its inception in Houston, Texas less than six years ago the growth of the association has been steady. One indication of the progress made is in the fact that registration at the 1949 Cincinnati Conference was greater than the membership early in 1947.

Growth in NACE Membership

DATE Jan. 1:	Corporate and Associate Members	Active and Junior Members	Total Members
1944	0	19	19
1945	0	342	342
1946	0	527	527
1947	46	760	806
1948	152	1145	1297
1949	252	1550	1802
Aug. 1: 1949	271	1820	2091

Metropolitan New York Section will hold its first fall meeting September 28 at the Building Trades Employers' Association, 2 Park Ave., New York, N. Y. with C. P. Larrabee, of the research laboratory of Carnegie-Illinois Steel Co., Vandergrift, Pa. as speaker on the topic, "Atmospheric Corrosion." This meeting will begin the second year of the section. New officers will be inducted.

New officers of the Sabine-Neches Section elected at the May meeting, who will assume their duties with the first fall meeting of the section scheduled to be held September 22 at the Orange Airport Cafe are M. A. Furth, Pure Oil Co., Nederlands, Texas, chairman; D. L. Burns, Gulf Oil Co., Port Arthur, Texas, vice-chairman and R. S. Freeman, Cities Service Refining Co., The Tutwiler Refinery, Lake Charles, La., secretary-treasurer.

Working committees now are being formed and their composition soon will be made public.

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A list of addresses of new members and changes of addresses of old members will be a monthly feature of CORROSION magazine beginning with the September issue.

Short Course Registration At Austin Is Arranged

Registrations still are being received by mail from persons who plan to attend the Short Course in Corrosion to be held September 12-16 inclusive on the campus of the University of Texas, Austin. The course is designed for persons who must deal with corrosion in their daily work and who desire more information in order to deal with it more efficiently. It should be of value to persons who feel that a refresher course and the opportunity for discussion with other corrosion engineers would be beneficial. For this reason the course is divided into Fundamentals, Metallurgy, Types of Corrosion, Corrosion-resistant Metals, Cathodic Protection and Chemical Treatment.

Lecturers have been selected for their ability to present the practical side of the specialties on which they will speak.

Applications for registration will be sent on request from Central Office NACE, 919 Milam Building, Houston 2, Texas. It will be advisable not to send requests for applications after September 5, but instead to attend without registration in advance. It is urged, however, that arrangements for lodging be made in advance.

Those who wish to do so may register at the University, at Room 118 Chemistry Building before class time Monday, September 12.

Corrosion Conference Is Held by Gas Group

A round table conference on corrosion under auspices of the Southern Gas Association was held July 22 at the St. Charles Hotel, New Orleans, with H. V. Beezley of United Gas Pipe Line Co., Shreveport, presiding. About 25 were present for the all-day session, one of 27 similar conferences held or scheduled during 1949 dealing with phases of the gas industry.

Principal topics were instruments, cathodic protection of distribution systems, pipe line insulation, coatings, cathodic protection coordination and galvanic anodes. The whole program consisted of informal discussions and no prepared papers were presented.

NACE CALENDAR

NORTH EAST REGION—Board of trustees meetings scheduled September 22 and November 18.

METROPOLITAN NEW YORK SECTION—Meetings are scheduled Sept. 28 and Nov. 9, 1949; Feb. 8 and May 10, 1950.

PHILADELPHIA SECTION—An Inspection tour of Lukens Steel Co., will be held September 20.

GREATER ST. LOUIS SECTION—Meets third Monday monthly. No meetings June, July, Aug., and September.

SHREVEPORT SECTION—Will hold no meetings during July and August. Regular meeting day is second Thursdays monthly.

TULSA SECTION — Meets Second Monday monthly.

NORTH TEXAS SECTION—Will hold its next meeting during September.

SABINE-NECHES SECTION—Meeting scheduled September 22 at Orange Airport Cafe, Orange, Texas.

SAN FRANCISCO BAY AREA SECTION—Meets alternate months, except August. Next meeting will be held in October, first Tuesday, unless changed later.

Ballots on Association Articles Changes Counted

Tabulation of the returned ballots received at Central Office NACE on the amendments to the articles of organization sent to the membership on June 10, 1949 showed approval of Alternate 1A of Amendment No. 1, Amendments 2 to 9 inclusive and Amendment 10.

Tellers appointed in accordance with Article VI of the present articles of organization were Lyle R. Sheppard, R. A. Brannon and W. E. Waldrip. Their report was made to the board of directors on July 19, 1949.

North East Region's new chairman, succeeding R. H. Lynch, who has been named director of the region by the directors, is N. P. Peifer, Manufacturers Light and Heat Co., Pittsburgh, Pa. Mr. Peifer's appointment was automatic under region by-laws. This leaves the region vice-chairmanship vacant, and it is the intention of the trustees to let it remain vacant for the balance of the year. Mr. Lynch succeeded Ed Noppel, who resigned as regional director to accept the chairmanship of the national association's policy and planning committee.

Reports of Technical Practices Sub-Committees Being Collected for Annual Publication

KENNETH TATOR

New chairman of Technical Practices Sub-Committee 6—Protective Coatings, succeeding G. W. Seagren. Mr. Tator is head of the corrosion engineering firm of Kenneth Tator Associates, Coraopolis, Pa., which specializes in corrosion and abrasion protection methods. He is a registered chemical engineer, was graduated from Reed College, with a B.A. and from M.I.T. with an M.S. in chemical engineering. He has worked in various capacities with Dewey & Almy Chemical Co., Cambridge, Mass., the War Production Board, founded Industrial Lining Engineers, Inc., and is skilled in rubber compounding and processing, emulsion and dispersion techniques, colloidal processing, canning and can manufacture, among others.

Corrosion Will Publish Membership List Changes

Beginning with this issue of CORROSION magazine the names of new members, with their addresses, and changes of address will be published. The compilation will represent the collected data on membership available at time of publication.

This information is being published in the belief it may simplify the problem of secretaries of sections and regions in keeping track of membership changes. Heretofore Central Office NACE has undertaken to advise regional secretaries of changes, but it has proved difficult to extend this information to the section secretaries.

The data, arranged by states, and alphabetically by names within states, will appear each issue in the news section. Location of the list is given in the index.

All persons in the association interested in keeping their membership mailing lists current are urged to use this convenient published list.

Reports from all Technical Practices Sub-Committees are being collected by Dr. Mars G. Fontana, chairman of the committee in order that the reports may be published simultaneously this year. Some of the data already has been collected by Dr. Fontana and every effort is being made to expedite collection of the remainder so that each sub-committee may have a report in the volume.

Plans for these reports include prior publication in CORROSION magazine of shorter ones and publication of condensations where they are judged too long for publication in the official journal. First of the reports to be published in CORROSION is that for T.P.-12—Electrical Grounding Practices, which may be found in this issue on Page 311. The title of this committee, effective at once, has been changed to "Effect of Electrical Grounding on Corrosion."

Another change in committe title has been announced. This is for T.P.-1—Corrosion of Oil and Gas Well Production Equipment. The new title is "Corrosion of Oil and Gas Well Equipment" eliminating the word "production."

Two new Technical Practices Sub-Committees were formed at the 1949 Cincinnati conference. They are:

TP-14—Instruments for Corrosion Measurements. Chairman Raymond F. Hadley, Susquehanna Pipe Line Company, Philadelphia, Pa. The committee plans to evaluate instruments designed to make measurements in corrosion testing.

TP-15—Corrosion Control in the Transportation Industry. Chairman, Dr. Merritt A. Walliamson, Pullman-Standard Car Manufacturing Co., Hammond, Ind. The committee's scope includes corrosion problems in the transportation industry exclusive of marine and pipe line industries.

Mudd & LaQue to Speak On Basin Tour Program

O. C. Mudd, of Shell Pipe Line Corp., Houston and treasurer of NACE will give a resume of the association's progress and F. L. LaQue International Nickel Co., New York, past president of the association, will discuss "Some Notes on How Coatings May Affect Corrosion," during the Third Annual Permian Basin Corrosion Tour to be held September 27-30 at Midland, Texas.

Exhibits, which will be in the City-County Auditorium and American Legion Hall, will be open to the public.

Eighteen tours in air conditioned buses will be a feature of the event.

This is the first of the Permian Basin events at which scheduled addresses have been given. A third speaker's name is to be announced later.

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CORROSION magazine seeks for publication notices of meetings of associations other than NACE which conduct corrosion investigations and research work. Members who know of such activities not reported in CORROSION are asked to notify Central Office so steps may be taken to publish the information.

Five Named to 1950 Conference Symposia

South Central Region Program Distribution Due Before September 15

Programs for the annual meeting of South Central Region to be held at Hotel Adolphus, Dallas, Texas, October 3-4, 1949 are scheduled to be distributed before the middle of September to all NACE members in the region and to a long list of others including many from other regions.

In common with other similar meetings of NACE subdivisions is open to anyone interested in the problem of corrosion, whether or not he is a member of the association.

Tentative information about the meeting is as follows:

Sunday, October 2—Meeting of regional management and executive committees; TP-2—Galvanic Anodes and TP-3—Anodes for Impressed Currents.

Registration begins at 2 p.m., a meeting of the regional officers is scheduled for 3 p.m., and of the nominating committee for new officers at 4 p.m.

Monday, October 3—General regional membership meeting, including a report by the officers and concluding with election of new officers. Monday afternoon will be devoted to a Corrosion Panel Discussion and beginning at 6:15 p.m. there will be a fellowship hour and buffet supper.

Tuesday, October 4—Will be devoted entirely to presentation of technical papers.

Work on New Humble Pipe Line Is Scheduled

An 18-inch, 375-mile oil pipe line between Kemper, Reagan County, Texas and Satsuma, 20 miles north of Houston will be started in 1949 by Humble Pipe Line Co. Estimated cost is $3,000,000. Designed capacity is 95,000 barrels daily with one intermediate pumping station and 120,000 barrels and a day with two. At Satsuma the line will connect with other Humble lines.

Part of Humble's old system from West Texas to Baytown by way of West Central Texas will be taken up when the new line goes into operation.

Diffraction Conference

Special sessions are planned for technical papers about metals structures, surface films on metals instrumentation techniques and general diffraction at the Seventh Annual Pittsburgh Diffraction Conference, Mellon Institute of Industrial Research, Pittsburgh, Pa., November 7-8, 1949.

General chairman is Dr. E. E. Stickley, Pittsburgh Plate Glass Co., Creighton, Pa., and chairman of the program committee is R. K. Scott, Hall Laboratories, Inc., Box 1346, Pittsburgh 30, Pa.

TECHNICAL PAPERS
Scheduled for
October Publication

"The Deterioration of Steel Sheet Piling at Palm Beach, Florida," By C. W. Ross.

"The Electrochemical Behavior of Zinc and Steel in Aqueous Media," By R. B. Hoxeng and C. F. Prutton.

"The Study of Corrosion in the Colleges," By Hugh J. McDonald.

TP Reports Numbering System Is Outlined

Adoption of a system of numbers for published reports of NACE technical sub-committees which are designed to facilitate reference to them is announced concurrently with the publication of the report of TP-12—Electrical Grounding Practices. This system is as follows:

1. It applies only to reports published either in CORROSION magazine or separately.

2. The numbers will be assigned both to complete reports and to digests of reports published in CORROSION magazine. In the case of a digest, the designation will be followed by the word "digest."

3. Letters of the alphabet will take place of years: For example, the letter capital "A" has been assigned as the substitute year 1949. All reports published during the calandar year 1949 will bear the designation "A."

4. The next unit is the number of the committe, for example, the report by TP-12 will be identified by the following "A-TP-12."

5. A third unit, when used will be the word "digest," which will follow the letter and committee number on those reports which are published in CORROSION in digest form. In this connection, because it is intended that full reports only will be included in the annual bound volume of committee reports, the digests probably will not appear elsewhere after being published in CORROSION.

6. Where more than one report is published during a year a third component will be added. This will consist of a description of the report, for example, assuming TP-12 has a second report published during 1949, the full designation of that report would be "A-TP-12—Second Report." It is believed this will occur infrequently, however.

Adoption of this system of designation will simplify reference to the various reports in the future and eliminate the possibility of confusion of titles.

The number will appear in most cases near the upper right hand corner of the report.

C. E. Maier, Continental Can Co., Chicago, Ill., has accepted appointment as chairman of the Food Industry Symposium to be held during the 1950 NACE Conference in St. Louis, Mo. April 4-7 at the New Jefferson Hotel. F. L. LaQue, International Nickel Co., Inc., New York, will be chairman of the round table session at which current industrial corrosion problems will be discussed.

These acceptances have brought to nine the number of sumposia in which partial or full acceptance of supervisory responsibility has been reported. The two roundtable sessions' chairmen now have been named, F. J. McElhatton, Panhandle Eastern Pipe Line Co., Kansas City, Mo. having accepted the post of moderator for the Pipe Line session.

Protective Coatings

Kenneth Tator, Montour Street Extension, Coraopolis, Pa. and George Diehlman, National Lead Co., Brooklyn, N.Y. have been named co-chairmen of the protective coatings symposium to assist R. P. Devoluy, chairman.

Oil and Gas Industry

T. S. Zajac, Shell Oil Co., Houston and M. S. Northup, Standard Oil Development Co., Elizabeth, N.J. have been named co-chairmen to the oil and gas industry symposium to assist E. Q. Camp.

A decision which is expected to have the result of assuring earlier publication in the association's official publication CORROSION of papers presented at the annual conference has been made. This calls for presentation for publication review of conference papers immediately upon receipt by Central Office NACE rather than delaying their consideration for publication until after the conference.

San Francisco Site of ASTM October Meeting

Material of interest to NACE members is scheduled for presentation during the First Pacific Area National Meeting of the American Society for Testing Materials in San Francisco, Cal., October 10-14 inclusive. Sessions October 10 cover Plasticty and Creep of Metals and Fatigue of Metals; October 11, Dynamic Stress Determinations and Applications of Statistics; October 13, a Symposium on Cast Iron, sponsored by ASTM Committee A-3 on Cast Iron.

All engineers, technical people and others concerned with materials are invited to attend. Copy of complete program can be secured by writing ASTM headquarters, 1916 Race Street, Philadelphia 3, Pa. Duplicated copies of the papers will be available to registrants.

"Unified Screw Thread Standards," a new booklet published by the National Bureau of Standards and available from Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., at 30 cents a copy, gives proceedings of unification accord meetings among British, Canadian and American authorities.

Electrochemical Society Corrosion Division Symposium Scheduled October 13 in Chicago

The annual symposium of the Corrosion Division of The Electrochemical Society will be held during the society's annual meeting in Chicago, Ill., October 12-15. Dr. Mars G. Fontana, Ohio State University, is chairman of the division. The corrosion papers tentatively scheduled to be presented on Thursday, October 13.

"Effect of Oxygen Inhibition on Corrosion by Nitrates," by M. Cohen, R. Pyke and Marier.

"Chemical Properties of the Intermetallic Compounds Mg_2Sn and Mg_2Pb," by H. H. Uhlig and Robertson.

"The Dissolution of Aluminum in Sodium Hydroxide Solutions—II," by M. A. Streicher.

"Effect of Adsorbed Polar Organic Compounds on Activity of Steel in Acid Solutions," by Norman Hackerman.

"A Unified Mechanism of Passivity and Inhibition—Part II," by R. B. Mears and R. H. Brown.

"Intensity and Distribution of Underground Corrosion Currents," by Walter Beck.

"The Effect of Amines on the Electrode Potential of Mild Steel in Tap Water and Acid Solutions," by J. D. Sudbury and N. Hackerman.

Additional papers also are being considered by the publication committee.

In addition to the corrosion division symposium, the Electro-organic and Electrodeposition Divisions are holding symposia and the Battery Division is holding a round-table discussion on subjects of specific interest to battery manufacturers.

Technical meetings and several plant trips are open to all interested who register. The program booklet listing all papers to be presented, along with other detailed information about the meeting will be available the latter part of September. Dr. H. B. Linford is secretary of the society with offices at 225 West 102nd St., New York 25, N.Y., and C. A. Hampel, Armour Research Foundation is chairman of the Chicago Section convention committee.

Basin and Ozark Line To Midwest Is Opened

The Texas Pipe Line Co., Shell Pipe Line Corp., Sinclair Refining Co. and Empire Pipe Line Company dedicated June 11-14 their joint line which connects the Permian Basin and the Midwest. Known as the Basin and Ozark Pipe Line Systems, the two provide continuous transportation for crude oil from Jal, New Mexico, via. Cushing, Okla. to Wood River and Patoka, Ill. Additional connections are provided at Wink, Midland and Wichita Falls and at the northern termini to other pipe lines.

The Basin System from Jal to Cushing is owned by the four principals and that from Cushing to Wood River by Shell and Texas and from Wood River to Patoka, by Texas.

The section from Jal to Midland is 20 inches; thence to Wichita Falls 22 inches; thence to Cushing 24 inches. Final throughput capacity to Cushing will be 241,000 barrels daily. The Ozark system has a diameter of 22 inches and the section from Wood River to Patoka also is 22 inches. Initial designed capacity of this section is 186,000 barrels daily, which can be increased to 260,000 barrels daily if intermediate pumping stations are added.

The line is featured by extensive use of electrically-operated and remotely-controlled valves and switch-gear. The thirteen electrified stations have a full load demand of about 38,000 kilowatts. Main line pumps at Jal are gas driven.

The 1002-mile line was started in November, 1947, consumed 200,000 tons of pipe and crossed 14 major rivers.

Coating used on the line was coal tar enamel, reenforced with glass fiber and with an asbestos felt outside cover.

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Section and region secretaries are urged to use forms provided by NACE for reporting meetings and attendance at meetings to Central Office and CORROSION magazine.

NACE NEW MEMBERS and ADDRESS CHANGES

NEW MEMBERS

ALABAMA

VINES, E. D., Koppers Co., Inc., Tar Products Divn., Woodward, Alabama.

BAHREIN ISLAND

DAVIS, RUSSELL L., Bahrein Petroleum Co., Awali, Bahrein Island, Persian Gulf.

CALIFORNIA

CLARK, MANLEY H., Clark Metallizing, Inc., 506 30th St., Newport Beach, Cal.

KNUDSEN, H. A., East Bay Municipal Utility District, 512 Sixteenth St., Oakland, Cal.

LACY, J. GLEN, American Pipe & Const. Co., Amercoat Divn., 4809 Firestone Blvd., South Gate, Cal.

MORRIS, CLARENCE S., Tretolite Co. of California, 5515 Telegraph Road, Los Angeles 22, Cal.

STORM, ARTHUR E., Tide Water Associated Oil Co., Associated, Cal.

ENGLAND

HURST, S., Tretol Limited, 12-14 North End Road, London, England.

LOUISIANA

ABRAHAM, MACK, Cities Service Refg. Corp., Butadiene Plant, Lake Charles, La.

MARYLAND

MAYER, WILLIAM J., A. M. Byers Co., 10 E. Lexington St., Baltimore 2, Maryland.

MASSACHUSETTS

PIKE, DONALD B., Stone & Webster Engineering Corp., 49 Federal St., Boston, Mass.

NEW JERSEY

CARR, JOSEPH A., Village of Ridgewood, 38 Oak St., Ridgewood, N. J.

HULL, GEORGE C., JR., Anglo-American Varnish Co., 55 Johnson St., Newark 5, N. J.

NEW YORK

BARRON DONALD W., Albert F. Ganz, Inc., 511 Fifth Ave., New York 17, N. Y.

McWATERS, RAYMOND J., Metallizing Engineering Co., Inc., 38-14 30th Street, Long Island City 1, N. Y.

SKINNER, EDMOND N., JR., International Nickel Co., Inc., 67 Wall St., New York 5, N. Y.

OHIO

PRINGLE GEORGE H., The Mead Corporation, S. Paint Street, Chillicothe, Ohio.

PENNSYLVANIA

BENEDICT, RISQUE L., A. V. Smith & Co., 370 Trevor Lane, Bala-Cynwyd, Pa.

HENKE, ROBERT H., Allegheny Ludlum Steel Corp., Brackenridge, Pa.

HUTZLER, GEORGE J., Rohm & Haas Co., 5000 Richmond St., Philadelphia 32, Pa.

PETTIBONE, JOHN S., American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.

ROYSTON, JOHN H., Royston Laboratories, Inc., 128 First St., Blawnox, Pa.

TEXAS

BEECHERL, LOUIS A., JR., Republic Natural Gas Co., Route 2, Box 63, Corpus Christi, Texas.

CHATELAIN, JOHN B., Freeport Sulphur Co., P. O. Drawer A, Freeport, Texas.

KEITH, CECIL S., Keith-Kote, P. O. Box 298, Grand Prairie, Texas.

RAY, EDWARD B., Republic Natural Gas Co., P. O. Box 1644, Midland, Texas.

ROSE, LEONARD M., Corrosite Corporation, 2018 Capitol Ave., Houston, Texas.

SMITH, SIDNEY V., Plastic Coating Corp., P. O. Box 13127, Houston 19, Texas.

SPENCER, L. S., Secco Pipe Coating Co., Inc., 500 N. Greenwood St., Houston, 10, Texas.

CHANGES OF ADDRESS

(Old Address Follows New Address in Parenthesis)

REMOVALS FROM: Camden, N. J.; Tulsa, Okla.; Jackson, Miss.; Kansas City, Mo.

CALIFORNIA

NICHOLSON, JAY T., National Aluminate Corp., 425 So. Western Ave., Los Angeles 5, Cal. (918 S. Gramercy Drive, Los Angeles 6, Cal.)

KENTUCKY

HURTGEN, ARCHIBALD, P. O. Box 484, Louisville 1, Ky. (Henry Vogt Machine Co., P. O. Box 484, Louisville 1, Ky.)

TROUPE, RALPH A., Department of Chemical Engineering, Speed Scientific School, University of Louisville, Louisville, Ky. (2826 Stevens St., Camden, N. J.)

LEBANON

HORNE, ALBERT N., Trans-Arabian Pipe Line Co., Box 1348 Beirut, Lebanon. (Texas Empire Pipe Line Co., Box 2420, Tulsa 2, Okla.)

LOUISIANA

BIENVENU, ALAN L., 101 Vine, Maplewood, La. (Box 2581, Maplewood, La.)

NEW YORK

SHAW, A. G., Ebasco Services, Inc., 2 Rector St., New York, N. Y. (Care Mississippi Power & Light, Jackson, Miss.)

OHIO

SHARPNACK, E. V., Reynolds Metals Co., 2535 Gilbert Ave., Cincinnati 6, Ohio. (4017 Carew Tower, Cincinnati Ohio)

TEXAS

HALTOM, J. MYRL, 3809 Centenary, Dallas, Texas. (2651 Burlington, Dallas, Texas)

CAMPBELL, A. B., Natl. Assn. of Corr. Engrs., 919 Milam Bldg., Houston 2, Texas. (905 Southern Standard Bldg., Houston 2, Texas.

JUDAH, MELVIN A., 919 Milam Bldg., Houston 2, Texas. (905 Southern Standard Bldg. Houston 2, Texas)

THORNEY, CHARLES E., JR., NACE, 919 Milam Bldg., Houston 2, Texas. (905 Southern Standard Bldg., Houston 2, Texas)

WASHINGTON, D. C.

DIETSCH, F. F., Reynolds Metals Co., 417 Barr Bldg., Washington, D. C. (Reynolds Metals Co., Aluminum Divn., 916 Dwight Bldg., 1004 Baltimore, Kansas City Mo.)

NEW PRODUCTS—Materials—Service—Literature

Impartial surveys, analyses, recommendations and supervision of corrosion control methods and materials is offered by Kenneth Tator Associates, Montour Street Ext., Coraopolis, Pa. The firm's special field is identifying various corrosion sources within plants.

Kenneth Tator, formerly president of Industrial Lining Engineers, still will serve that company in a professional capacity. He is chairman of NACE Technical Committee on Protective Coatings, was a pioneer in the application of vinyl plastisols to corrosion prevention and has developed many other corrosion prevention methods. His associates' experience complements him in the fields of metallurgy, cathodic protection and testing.

G-E Permafil, a polyester-type resin for sealing porous, light metal castings has been announced by General Electric's Chemical Department, Pittsfield, Mass. The new material was developed to permit foundries to salvage castings which otherwise be rejected because of porosity. The material converts to a tough, clear solid, free of voids through the action of catalysts and heat, manufacturers claim.

Rhodes Potentiometer Voltmeters and the Shepard Conductivity-Restivity instrument are illustrated and explained in a 4-page folder entitled "Electrical Measurements" issued by Sensitive Research Instrument Corporation, 9-11 Elm Ave., Mount Vernon, N. Y. Uses of the instruments, especially in designing and installing cathodic protection systems for pipe lines, is explained briefly.

Efficient Production of cool dilute sulfuric acid from the required quantities of commercial strength acid and diluting water is possible with "Karbate" brand sulfuric acid diluting equipment manufactured by National Carbon Co., Inc., 30 East 42nd St., New York 17, N. Y., and described in catalog section M-8806A which is available on request.

Industrial Water hose designed for a wide variety of services are described in Catalog Section 4800 by B. F. Goodrich Co., Akron, Ohio. Construction, recommended uses and specifications are given.

Resistherm, a portable thermometric slide wire bridge designed for routine temperature measurements to ½ degree or .1 degree. It operates on 115-volt AC. Paul G. Weiller, 95 Broad St., New York 4, N. Y., is the manufacturer.

"Octanium" an Alloy of cobat, nickel, chromium, molybdenum, manganese, iron, beryllium and carbon is being used by Parker Pen Company as material for nibs on a new line of fountain pens. The company says the new material was adapted for pen-point use partly because its tensile strength exceeds that of gold and partly because it is non-corrosive and non-magnetic.

Plant Maintenance Show will be held Jan. 16-19, 1950, in the auditorium, Cleveland, Ohio, an announcement by Saul Poliak, Clapp & Poliak, Inc., 350 Fifth Ave., New York 1, N. Y., states. There will be no charge for either exhibit or conference attendance at the event which will be devoted to cost reduction through improved installation, operation and maintenance of equipment.

"Cathodic Protection of Galvanized Hot Water Storage Tanks by Use of Galvanic Magnesium Alloy Anodes," by D. J. Fergus, Research Engineer, The Cleveland Heater Co., 2310 Superior Ave., Cleveland 14, Ohio, a bulletin of 16 pages on the subject, is available on application to the above address for 25 cents.

Nylon Strip, currently being manufactured in widths up to two inches by Elastic Stop Nut Corp. of America at its Union, N. J., plant, is recommended by the manufacturer for uses in environments where its resistance to all common organic solvents and all but mineral acids, is valuable especially in food handling processes and as low-pressure bearing material used without lubrication.

Wood Vats for use in pickling operations and for the cleaning of electrically-welded tubes rolled from flat strip are detailed in Bulletin No. 22, which contains complete data on performance and application, and which may be had from Wendnagel & Co., Inc., 600 W. Cermak Rd., Chicago 16, Ill.

Spiral-Welded Stainless steel tubing, with perfect alignment of strip edges is produced in a new machine by the B & M Manufacturing Co., East Orange, N. J. and Grand Rapids, Mich. in sizes from ½-inch to 6-inch OD, with dimensional accuracy of .001 in the ½-inch and .002 in the 3-inch OD sizes. Because of exact control at the point of welding thinner wall sections may be handled, particularly in the larger diameters. One inch OD x .010 wall in type 304 stainless has been made on a production basis. Standard practice permits a 40 percent reduction by area by cold drawing of tubes directly from the welder.

Austenitic Cast ferrous alloy containing 19.50 percent chromium and 9 percent nickel, among other constituents is believed to have particular usefulness in applications requiring temperatures as low as —423° F. Lebanon Steel Foundry points to its use in storing liquid oxygen for rocket engines at high pressures at —298° F. No structural changes, down to —423° F. and an increase in hardness and tensile strength directly proportional to the decrease in temperature is claimed. The same alloy also is being used for high temperature environments in jet and gas turbine units.

Known Applications and technical information on low-temperature-melting Cerro Alloys are listed in a new 4-page folder by Cerro de Pasco Copper Corp., 40 Wall Street, New York 5, N. Y.

"Casting Stainless Steel Centrifugally," and "Casting Centrifugally in Permanent Metal Molds," reprints of information on this subject are available on application to The Cooper Alloy Foundry Co., Hillside, N. J.

Graphite Films of 0.00015 to 0.0005 inch with high resistance to abrasion, diffusion into the coated surface, and application by spray or dip following normal surface preparation on metal, plastics, rubber and ceramics are possible with its patented process, according to Electrofilm Corp., 7116 Laurel Canyon Blvd., North Hollywood, Cal. The process is offered on license to manufacturers or can be applied by the firm.

Corrosives don't touch the metal parts of the new pump developed by the Vanton Corp., Empire State Building, New York City. The pump consists of an eccentric rotating within a cylindrical space with separate ports for incoming and outgoing material. The eccentric is encased in a flexible sheath which is attached to the pump body at the top in such a manner that when the eccentric rotates the contents of the pump cylinder are pressed through the exhaust port.

Fiberglas Cloth impregnated "Silastic" tape especially manufactured for application by vulcanizing has been announced by the Irvington Varnish and Insulator Co., Irvington, N. J. The material consists of Fiberglas cloth coated on both sides with a rubberlike dielectric. On one side the material is completely cured and on the other only semi-cured. After application as insulation and heated the mass solidifies. The completed job is moisture and oil-resistant.

Excellent Bond obtained by chemical action with the surfaces of zinc, lead, cadmium, aluminum, nickel, copper, stainless steel, galvanized metals, magnesium and others is claimed for Cyclon "WPS" Primer manufactured by Munray Products Inc., 12400 Crossburn Ave., Cleveland 11, Ohio. The "Cyclon Selective Coating System" involves application of a "Tie Coat" between the bonding coat and the top coating. The thermoplastic resins used in the products offer high resistance to corrosives, the company claims.

Steel Founders Society of America is offering a new illustrated booklet detailing the advantages of using steel castings. It is intended as a guide to design engineers. Copies may be obtained from F. Kermit Donaldson, Executive Vice-President, Steel Founders Society of America, 920 Midland Bldg., Cleveland 15, Ohio.

Recording Voltmeters for use in recording electrolysis surveys of potentials of underground structures are offered by The Bristol Co., Waterbury 91, Conn. The company's Bulletin E1108, dated June, 1949 is available on request.

PERSONALS

Arthur R. Fox, NACE member, has established offices as a corrosion consultant at 1833 Berryman Street, Berkeley, California. Mr. Fox is agent for the Fisher M-Scope pipe locator and leak detector.

Jack F. Brossart, until recently general sales manager of Industrial Filter & Pump Mfg. Co., Chicago, Ill. has been appointed Pacific Coast manager for the company. Harold W. Faint, recently manager of the Ion Exchange Department has been appointed general sales manager.

Nathan Schofer, formerly chief corrosion engineer for Cities Service Refinery Corp. at Lake Charles, La. for a number of years, has joined the staff of Ebasco Services, Inc., New York, N. Y. for work with Ebasco's group of corrosion engineers. He will specialize in corrosion investigations and corrosion mitigation in industrial processes.

Mr. Schofer was employed in the gas utility industry 13 years and for two years with M. W. Kellogg in the design of petroleum refinery units. He is chairman of South Central Region NACE and holds a gas engineering degree from Johns Hopkins University.

George W. Altman has been named foundry engineer for The National Radiator Co., Johnstown, Pa.

W. A. Severance has been named chief chemist in charge of research and development, product control and special customer problems in the field of corrosion-proofing by the Ceilcote Co., Rockefeller Bldg., Cleveland, Ohio.

Herbert H. Walther, Jr., has been named development engineer at Dowell, Inc., Richmond, Va. B. E. McCann, from Flora, Ill., is in charge of Dowell's new station at Sullivan, Ind.

Charles Turner Davis, 53, sales supervisor for Barrett Division of Allied Chemical and Dye Corp., a native of Maine, but a resident of Texas for over 22 years, died at his Houston, Texas, home July 27. A member of the Guild of Ancient Supplers, and of NACE, he formerly was employed by Dresser Manufacturing Co. for about 20 years. Surviving besides his widow are two daughters and two sons in Texas; a sister in Maine and a brother, also in Texas.

Harry A. Cooper, president of the Cooper Alloy Foundry, Hillside, N. J., has been elected president of the Alloy Casting Institute during the annual meeting at Colorado Springs, Col.

S. R. Simmons, Shreveport, La. has been named assistant manager of the Southern division in addition to his present duties as division general superintendent and **Joe C. Rawlins,** Tulsa, present chief engineer moves to Shreveport as assistant to the manager of the Southern division of Interstate Oil Pipe Line Co.

Steel Grit Cleaning... Means Better Bond of Coating by standard pipeprotection inc.

STEEL GRIT ... used in two Wheelabrator cleaning machines, provides the ideal method of cleaning all your pipe, ... every joint ... a positive method of removing all mill scale and rust.

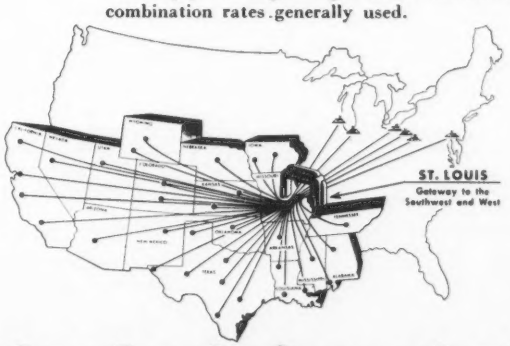
In evaluating the bond of protective coatings to metal surfaces ... the outstanding metal working industries rate steel grit as 100% efficient, while other methods tend to polish the surface and reduce bond performance.

Pre-warming and drying of pipe before cleaning and priming ... are a part of the Standard Procedures established by ***standard pipeprotection inc.*** to bring you uniform coatings of the highest quality, at no increase in cost.

STORAGE-IN-TRANSIT ... You can store your pipe in our yard up to 12 months without freight penalty ... while determining final destinations ... Through freight rates via our Saint Louis plant and our storage facilities save you money.

Wire, Phone or Write Now for Schedules

Immediate shipment or stop-over up to 12 months is permitted under existing railroad tariffs. When you ship your pipe through the Saint Louis Gateway ... You enjoy "through freight rates" instead of higher combination rates generally used.



standard pipeprotection inc.

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Corrosion Abstracts

COATINGS

The Weathering Resistance of Phosphated Steel. (In German.) GERHARD SCHIKORR. *Metalloberflache,* **1,** 188-190 (1947) Aug.

Outlines results of extensive research done to compare the effectiveness of different commercial phosphating agents, including one cold-process agent. Results are tabulated and graphed.—BLR.

The Electrodeposition of Alloys from Aqueous Solutions. (I, II.) Johannes Fischer. *Metalloberflache,* **1,** No. 10, 229-234; Nos. 11/12, 252-256 (1947).

(I) The structure of the deposit, the conditions of deposition, and general methods of operating the baths are described. (II) Typical bath compositions, working temp., voltages, and c.d. are given for the deposition of: 1) fine gold, 14 ct. gold, and gold colored by additions of copper, lead, or nickel; 2) pure silver, binary alloys or silver with nickel or cadmium, ternary alloys with rhodium and palladium, and with gold and zinc, and a quaternary alloy with gold, palladium, and tin; 3) copper and its alloys with zinc or cobalt; and 4) iron-cobalt, iron-nickel, nickel-cobalt, and an alloy containing copper 29, nickel 68, and iron 3%.—MA.

The Mechanism of Action of Metal Protective Paints. A. C. Elm. *Paint, Oil and Chem. R.,* **111,** No. 17, 16, 32-34+ (1948) Aug. 19.

The article discusses the various hypotheses and theories as to the corrosion preventive or inhibitive action of metal protective paint. Red lead paint, chromate paint, metal powder paint, and barrier coatings are discussed in detail. The conclusion is that none of the hypotheses advanced for the explanation of the mechanism of action of metal protective paints entirely satisfies all of the known facts and observation and further experimentation is necessary to advance the hypotheses of corrosion protection of metals by organic coatings and to bring them closer to the status of a dependable theory.—ALL.

Uber die Haltbarkeit Elektrolytisch Verzinkter Bleche in Verschiedenen Angriffmitteln. (The Resistance of Galvanized Sheets to Different Corroding Agents.) EISENTECKEN, F., FORSCHUNGSINSTITNT, Dortmund, Ger., Office of Technical Services, PB-73505, Frames 889-896 (1940) Feb.

The thickness of zinc coatings varies within wide limits because of the scattering effect of the galvanizing bath. The protective layer is not resistant to fruit juices and to candied fruits, since the zinc is dissolved by the free acid present. The zinc coating is unstable when attacked by some types of organic agents, but is durable when exposed to benzol, gasoline, or their mixtures when free from alcohol and water. The corrosion behavior in general is independent of the coating thickness.

Tensile and cupping test values on sheets plated with 20, 30, 40, 50, 70 and 80 g of zinc per sq. m. do not depend upon the coating thickness. In longitudinal samples, however, the elastic extension increases with increased layer thickness, but the number of alternate bendings necessary to produce failure seems to decrease. Since thickness varies widely within the single sheets, a clear relationship between coating thickness and rate of fracture cannot be obtained.

The thickness of galvanic coatings, determined on a series of segments along the diagonals of sheets, was greatest on the margins, then became gradually thinner towards the center; at the center the thickness again increased slightly. Approximately W-shaped curves are obtained when the coating thickness in gram per square meter is plotted against the distance from the margin. Galvanized sheets were exposed for 3 and 18 mo. to an industrial atmosphere, water vapor, fruit juices, candied fruits, waterglass, tar oil, linseed oil, lacquers, turpentine, benzene, gasoline, alcohol and fats. Tables, diagrs.—DPA.

Abstract Section Style Outlined

For ease in locating reference data, CORROSION uses a uniform style in its Abstract Section.

The abstracts first are broken down into major classifications of the more common types of corrosion literature. In each review the title of the article is presented in bold face type, followed by the author's name. The publication from which the article was abstracted is printed in italics and is abbreviated in most instances. Following this, in sequence, are the volume (bold face), number in the volume, pages, year and month of publication. In some instances a second reference will be listed in the same manner. This indicates that the article also was published or abstracted in another publication. A brief summary of the article follows the above information and it is concluded with an abbreviation indicating the source of the abstract and contributor. The meanings of these abbreviations usually are listed on the first page of the Abstract Section.

When seeking more detailed data about an abstract, best source of information is the publication in which the article appeared originally. (Listed in italics in the heading.) The contributor of the abstract also may be able to supply additional information. Addresses of most of these publications may be found in the reference section of most public libraries.

FUNDAMENTALS

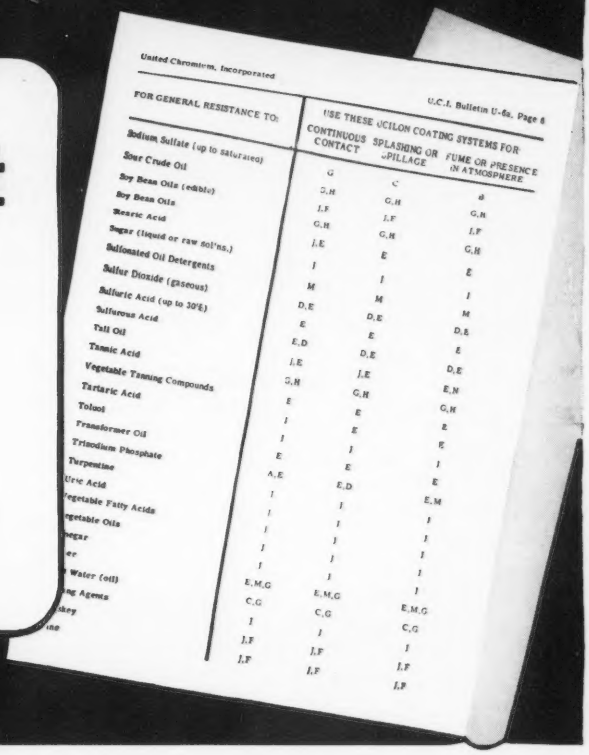
Optical Determination of Thin Films on Reflecting Bases in Transparent Environments. A. B. WINTERBOTTOM. Pittsburgh International Conference on Surface Reactions. *Proceedings,* 91-100 (1948).

The classical theory of metal and film optics is recapitulated, and its implications in connections with various optical methods of studying films and surfaces are indicated. The experimental technique of the determination of thin films in situ from the change produced in the reflection of a polarized wave is then outlined. Optical techniques are not advocated to supplant other methods of studying surfaces such as weight increment, gas absorption, electron diffraction, X-ray diffraction, and electrochemical analysis, but rather to supplement these in selected cases. In particular, the optical techniques are of value in making continuous studies of films in situ in transparent environments when conditions

Abbreviations at the end of abstracts indicate source of abstract and contributor; and are as follows:

AER	*Aeronautical Review,* Institute of Aeronautical Sciences, Inc.
ALL	*The Abstract Bulletin,* Aluminum Laboratories, Ltd.
AWWA	*Journal,* American Water Works Association
BLR	*Battelle Library Review,* Battelle Memorial Institute Library
BNF	*Bulletin;* British Non-Ferrous Research Association
CALCO	Calco Chemical Division, American Cyanamid Corp.
CE	*Chemical Engineering,* McGraw Hill Publishing Co.
CEC	Consolidated Edison Co. of New York, Inc.
EW	*Electrical World,* McGraw Hill Publishing Co.
GPC	General Petroleum Corp. of California
INCO	The International Nickel Co., Inc.
IP	Institute of Petroleum
MA	*Metallurgical Abstracts,* Institute of Metals, London, Eng.
ME	Marine Engineering
MR	*Metals Review,* American Society of Metals
NALCO	National Aluminate Corp.
NBS	National Bureau of Standards
RA	*Refrigeration Abstracts,* American Society of Refrigeration Engineers
RM	*Revue de Matallurgie,* Paris, France
RPI	*Review of Current Literature Relating to the Paint, Colour, Varnish & Allied Industries,* Research Association of British Paint, Colour & Varnish Manufacturers, London.
TDD	*Technical Data Digest,* Air Materiel Command—Technical Service Section
UOP	Universal Oil Products
No Code	*Current Technical Literature,* Bell Telephone Laboratories

How this booklet can help you BEAT CORROSION



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render the application of other methods difficult. Examples of applications are given.—MA.

The Rate of Oxidation of Nickel with Small Additions of Chromium or Manganese: Contribution to the Theory of the Oxidation Process. C. WAGNER AND K. E. ZIMENS. *Acta Chem. Scand.*, **1**, 547-565 (1947); *Nickel Bull.*, **21**, No. 7, 101 (1948).

Rates of oxidation in pure oxygen, at 1000° C., at 1 atm. pressure, were determined on: pure nickel; nickel-chromium, and nickel-manganese. The alloys contained, in each case, 0.3, 1.0, 3.0 or 10 wt.-% of the addition element. Rate of oxidation was measured by gain-in-weight determinations on plate specimens exposed in a tube furnace. Nickel containing 0.3-3% chromium oxidized twice as rapidly as pure nickel during the first hour of exposure. Additions of 10% of chromium resulted in rapid formation of oxide films of definite thickness, which remained unchanged up to 16 hr. under exposure in the conditions used. In the nickel-manganese series all the alloys oxidized more rapidly than nickel. In disagreement with earlier workers, it was found that the parabolic form of film-growth with time does not fit the observed data for nickel. The results obtained on the two types of alloy are treated mathematically, on the basis of mobility on the ions through an oxide lattice containing vacancies caused by the addition of cations of greater valence.—MA.

New Applications of the Theory of Oxidation of Metals Having Two Oxides. (In French.) GABRIEL VALENSI. *Rev. Met.*, **45**, 205-210 (1948) July.

Presents further mathematical development of the above theory, proposed by the author in 1936 for dry oxidation of metals having two oxides. Also presents experimental confirmation for the case of copper and its two oxides, CuO (cupric oxide) and Cu_2O (cuprous oxide). 16 ref.—BLR.

Anodic and Cathodic Polarization Curves for Iron and Copper in Sulfate Solutions Containing Oxidizing Agents. (In Russian). N. D. TOMASHOV, G. P. SINELSHCHIKOVA AND M. A. VEDENEEVA. *Doklady Akad. Nauk USSR (Reports of the Academy of Sciences of the USSR)*, **61**, 669-672 (1948) Aug. 1.

The above was investigated as an aid in determination of the mechanism of corrosion of copper steels. Data are graphed and discussed.—BLR.

Tracer Isotopes in Metallurgy. J. K. STANLEY. *Nucleonics*, **1**, No. 2, 70-77 (1947).

Briefly mentions the use of stable isotopes as tracers in metallurgical research and discusses the many applications of radio-active isotopes. The earliest use of radio-active materials as tracers was limited to naturally occurring elements, and the efforts of early workers in this field are reviewed; recent work with artificial tracers is more fully discussed under the following headings: fundamental diffusion studies, oxidation, corrosion, metallography, wear, process control, steelmaking, annealing, and chemical analysis. A bibliography of 40 references is included. —MA.

Passivation of Iron by Gaseous Oxygen. (In Russian.) H. A. SHUMILOVA AND R. KH. BURSHTEIN. *Doklady Akad. Nauk USSR (Reports of the Academy of Sciences of the USSR)*, **61**, 475-478 (1948) July 21.

The anodic passivation of iron in a dilute solution previously treated with gaseous oxygen was studied. The influence of temperature on the amount of electricity required to form ferrous hydroxide was determined. Data are graphed.—BLR.

The Contribution of Modern Physics to Metallurgy. F. SEITZ. *J. Applied Phys.*, **19**, No. 11, 973-987 (1948) Nov.

The importance of modern physics in the present development of metallurgy rests primarily upon two facts: Metals are composed of atoms and modern physics is concerned with obtaining a deeper understanding of the properties of atoms. The relation of physics to metallurgy is discussed under the following headings: atomic structure, crystal structure, the electrical conductivity of metals, the differences between metals and non-metals, magnetic properties, the migration of atoms in metals and the mechanical properties of metals.

One of the very great contributions of modern physics to metallurgy has been the development of methods for determining the arrangement of atoms in individual grains, notably X-ray and electron diffraction. Studies of the manner in which alloys scatter X-rays and electrons have yielded a great deal of useful information beyond the determination of lattice structures and the quantities, such as atomic diameters, that may be obtained from such structures. These lattices are often not perfect and an investigation of the scattering pattern may yield useful information concerning the nature of the imperfections. For example, duraluminum contains several percent of copper which is in perfect solution at high temperatures, but which precipitates near room temperature. Studies of the diffraction of X-rays by the alloy have yielded much important information concerning the precipitation process. Similar valuable information has been obtained regarding the distortion which accompanies the flow of metals under stress. Many important processes in metallurgy depend upon the fact that the atoms in metals are able to diffuse or migrate through the solid structure. For example, the hardening of duraluminum by heat treatment depends upon the fact that the rate of migration of atoms can be controlled by varying the temperature. The contribution of modern physics to the understanding of the diffusion process consists in the clarification of the mechanism by which atoms jump from one position in the lattice to another, the theory of thermal vibration of the atoms in solids being used to determine the way in which the migrating atoms receive the energy of thermal agitation which permits them to move.

The practical interest of metallurgists is focused more upon the mechanical properties of metals than upon any other attributes. Thus it has been shown (1) that metals, like most other solids, possess an inherent strength that is many times larger than the strength commonly observed, (2) a combination of X-ray and mechanical analysis shows that planes of the lattice slide past one another when metals flow ductily. Such flow requires the existence of stresses which act in the plane of flow, (3) the relatively great ductility of metals is intimately associated with the nature

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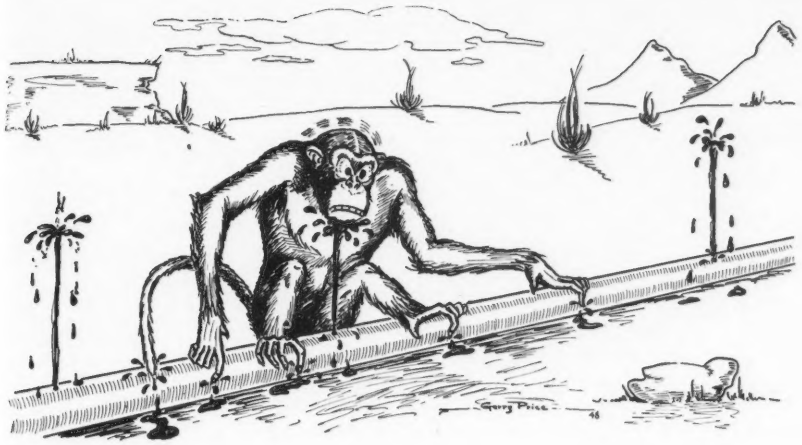

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of the bonding forces in these solids. The theory of dislocations has been developed and it appears that many of phenomena observed in connection with plastic flow can be explained with their use. This theory has to be further expanded and is one of the most important problems of the physics of metals.—ALL.

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Surface Layers of Crystals. *Nature*, **162**, No. 4120, 609-610 (1948) Oct. 16.

An X-ray method has been devised for measuring the thickness of the surface layers of crystals without altering it physically. The method involves the measurement of the variation in the intensity of X-ray reflection from a crystal, as the angle (ψ) between the surface and the Bragg reflecting planes, is varied. The surface of the crystal is cut so that it is inclined at an angle (ω) to the Bragg planes, and by rotating the crystal about an axis normal to the planes the effective value of (ψ) may be made to vary from zero to (ω) without disturbance of the surface. For a crystal with no surface inhomogeneities and expression has been developed for the ratio $1/1_0$ of reflected to incident beam intensity. If, however, there are surface inhomogeneities such that the reflection coefficient and absorption coefficient differ from the values appropriate to the main part of the crystal, then the variation of $1/1_0$ will follow a different law. Other assumptions may be made about the variation of the reflection coefficient with depth. An example is given for determining the thickness of the surface layer on a crystal of calcite ground and polished at an angle of 15° to a natural cleavage face.—ALL.

Electron Diffraction of Corrosion Films. *Metal Prog.*, **54**, No. 2, 234 (1948).

Summary of the paper "The Application of Electron-Diffraction Techniques to the Study of Corrosion Processes" by E. A. Gulbransen, presented before the National Association of Corrosion Engineers, April, 1948. It deals with the study of the dry oxidation of metals, in particular iron, by the transmission and reflection methods of electron diffraction and the interpretation of the results obtained.—MA.

Some Aspects of Internal Oxidation in Ag, Cu, Ni, and Fe Alloys. J. L. MEIJERING. Pittsburgh International Conference on Surface Reactions. *Proceedings*, 101-104 (1948).

M. describes the properties of alloys of silver, copper, nickel, and iron respectively with small amounts of other metals, after treatments leading to internal oxidation. The degree of dispersion of the oxide formed depends mainly on the difference in affinity for oxygen between the solute metal and the basis metal. Highly dispersed oxide causes considerable hardening of the alloy. In several cases inner oxide films develop, and these retard the progress of oxidation.—MA.

Influence of Additions to Lead-Antimony Alloys on the Performance of the Plates of Lead Storage Batteries. II. Investigation of the Kinetics of Corrosion. III. Overvoltage of Hydrogen on Alloys and Overvoltage of Oxygen on Oxidized Alloys. V. P. MASHOVETS AND A. Z. LYANDRES. (In Russian.) *Zhurnal Prikladnoi Khimii* (*Journal of Applied Chemistry*), **21**, 441-455 (1948) May.

In Part II, the characteristics of a series of lead-cadmium alloys containing various small admixtures of silver, bismuth, arsenic, iron and zinc with regard to their corrosion when used as storage-battery plates were determined. Lead containing no cadmium, but 0.33% calcium, was also evaluated. The protective effect of silver, the negative influence of bismuth, and the harmful effect of zinc are indicated. Lead-calcium appeared to be slightly more stable than lead-cadmium. In Part III, results of overvoltage measurements using specially developed apparatus and a similar series of alloys to that tested in Part II are given. Data are tabulated and graphed. 11 ref.—BLR.

Application of the Electron Microscope in Corrosion Studies. E. M. MAHLA AND N. A. NIELSEN. Pittsburgh International Conference on Surface Reactions. *Proceedings*, 60-66 (1948).

The use of the electron microscope in studies of metallic corrosion is exemplified by the authors' researches on stainless steel. Subjects investigated by this means include the intergranular corrosion of stainless steel, the effect of grain orientation on corrosion, and the properties of surface films formed at high and low temperature. The production of surface replicas of collodion, Formvar, and other resin films (which may subsequently be metal-shadowed to improve contrast and resolution) and of silica and oxide replicas is discussed, and examples are given of the use of most of these during the research on stainless steel.—MA.

An Oxide Replica Technique for the Electron Microscope Examination of Stainless Steel and High Nickel Alloys. E. M. MAHLA AND N. A. NIELSEN. (E. I. duPont de Nemours & Co.) Paper before Electron Microscope Society, Dec. 11, 1947. *J. Applied Phys.*, **19**, No. 4, 378-382 (1948) Apr.

An oxide replica method developed was suitable for the electron microscope examination of the surface of stainless steel, nickel, and high nickel alloys. Oxide film is produced on the metal surface by oxidation in a molten nitrate solution and is chemically stripped from the base metal by a bromine-methanol solution. Replicas of this type were used to study deep-etched structures, preferential etch attack and secondary phase

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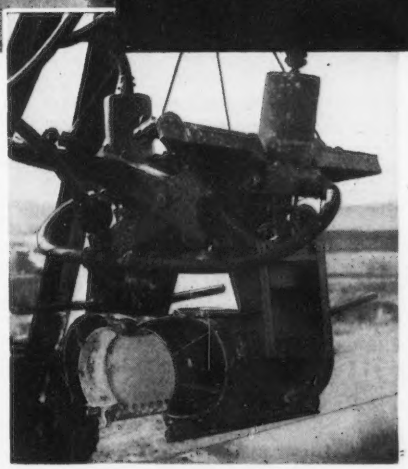

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Mechanism of the Rapid Oxidation of High-Temperature, High-Strength Alloys Containing Molybdenum. W. C. Leslie and M. G. Fontana. Am. Soc. Metals Preprint No. 26, 32 p. (1948); *Ind. Eng. Chem.*, **40**, No. 6, 103A-104A (1948).

An investigation was carried out on the extremely rapid oxidation of alloys containing more than about 3% molybdenum, which frequently occurs at high temperature. Most of the work was confined to an alloy containing chromium 16, nickel 25, molybdenum 6%, iron remainder, but numerous other complex high-temp. alloys containing molybdenum in quantities between 4 and 17% were also studied. The following factors were investigated. (1) the effect of other metal oxides or metal oxide vapors in contact with the specimen; (2) atmosphere circulation; (3) surface finish and protective coatings; (4) variations in composition (of the 16:25:6 alloy); and (5) the effect of stress. Most of the tests were carried out at about 900° C. Metallographic examinations were made on the oxidized specimens, and the oxide was studied by X-ray analysis and other means. The thermal dissociation of molybdic oxide according to the equation $MoO_3 \rightleftarrows MoO_2 + O$, was investigated by weight-loss determinations after evaporation in a platinum Knudsen cell under a vacuum. The very rapid oxidation occurs only when circulation of the atmosphere is very restricted, and is due to accumulation on the metal surface of gaseous molybdic oxide, which catalyses the oxidation of the iron in the alloy; thermal dissociation of the molybdic oxide accelerates the oxidation. Dissociation is appreciable above 815° C. and in vacuo is at least 0.7% at 831° C. and 6-7% at 941° C.; at atmospheric pressure dissociation is 0.6% at 831° C. and 1.24% at 941° C. Stress, surface finish, coatings, and minor composition changes have little effect, but the reaction is prevented by increasing the movement of the oxidizing gases across the surface of the specimen. The spongy oxide on the 16:25:6 alloy consists mainly of a mixture of iron oxides. The oxidation of iron, nickel, chromium, cobalt, and their alloys is increased by the presence of the oxide vapors of the metals, molybdenum, vanadium, lead, bismuth, and tungsten, but the extremely rapid spongy oxidation only occurs in alloys containing iron and molybdenum. The 16:25:6 alloy contains nitrides as well as carbides, the σ phase (FeCr) was not observed.—MA.

An Electron Diffraction Study of Oxide Films Formed on Hastelloy Alloys A, B, C and D. J. W. Hickman and E. A. Gulbransen. *J. Phys. & Colloid Chem.*, **52**, 1186-1197 (1948) Oct.

Results of above study are presented as existence diagrams on a time-temperature scale. Represents graphically the results which should be obtained under identical experimental conditions. Results are discussed at length. 12 ref.—BLR.

Low-Voltage Industrial Radiography with Fluorescent Screens. Robert L. Hay. *Non-Destructive Test*, **6**, No. 4, 29-32 (1948).

Standard non-screen (direct type) X-ray films exposed between calcium tungstate intensifying screens produce higher contrast and greater speed relative to the same film exposed under normal conditions. It is essential to mask the edges of the specimen effectively to avoid spoilage of the image by scattered screen light and X-rays. The tests described were made with steel, but also are applicable to brass and bronze specimens.—MA.

The Preparation of Single Crystals for the Study of Surface Reactions. Allan T. Gwathmey. Pittsburgh International Conference on Surface Reactions. *Proceedings*, 66-70 (1948).

Four methods of growing single crystals are considered: (1) from the molten metal, (2) in the solid state by the strain-anneal method, (3) by deposition from the vapor, and (4) by electrodeposition. For the study of the reaction of metals with gases or liquids the single crystals are converted into spheres (with a shaft extending from one point). In this way all possible crystal faces are exposed and it is possible to study the correlation between initial structure, changes in structure, and chemical activity. Machining and polishing methods are detailed for single crystals of copper, gold, aluminum, nickel, silver, chromium, cadmium, zinc, bismuth, tin, iron, lead, and indium. The two latter cannot be machined or mechanically polished without recrystallization. Electrolytic polishing is to be preferred for final surface preparation. During the study of a number of gas-metal reactions, it was found that definite facets are produced on a single crystal depending on the metal, the gas, and the crystal plane parallel to which the original surface was prepared, and within limits, independent of the initial surface preparation.—MA.

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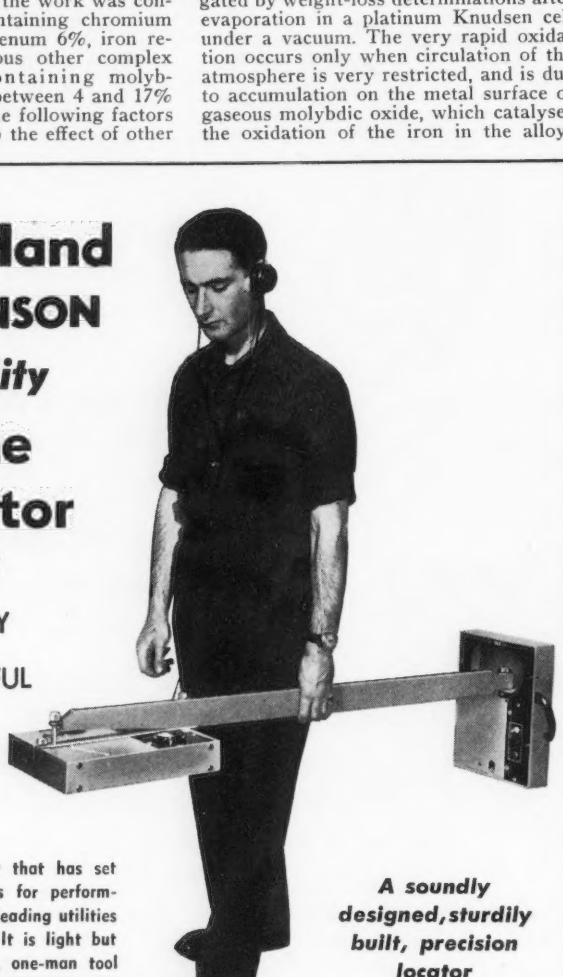

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Progress in the Study of Surface Oxidation of Metals and Alloys at Elevated Temperatures. (In French.) EARL A. GULBRANSEN. *Rev. Met.*, **45**, 181-204 (1948) July.

Presents results of a comprehensive study of the various factors affecting the above. The rate of formation of oxide was studied by use of the quartz microbalance, results being tabulated and graphed. Finally, results of electron-diffraction study at elevated temperatures of the structure of oxide films formed on iron, cobalt, nickel, chromium, 13%-chromium, iron, and 18-8 stainless steel are presented. (To be continued.)—BLR.

Progress in the Study of the Surface Oxidation of Metals and Alloys at High Temperatures. IV. Electron-Microscopic Study of Oxide Films Formed on the Surface of Metals and Alloys at Intermediate Temperatures. (In French.) (Concluded.) EARL A. GULBRANSEN. *Rev. Met.*, **45**, 287-300 (1948) Aug.

Photomicrographs are compared with electron-diffraction patterns for a variety of ferrous and nonferrous metals and alloys. On the basis of the results, the mechanisms of oxidation are discussed. Data are tabulated. 48 ref.—MA.

Reactions of Metals in High Vacua. EARL A. GULBRANSEN AND K. ANDREW. Pittsburgh International Conference on Surface Reactions. *Proceedings*, 222 - 236 (1948).

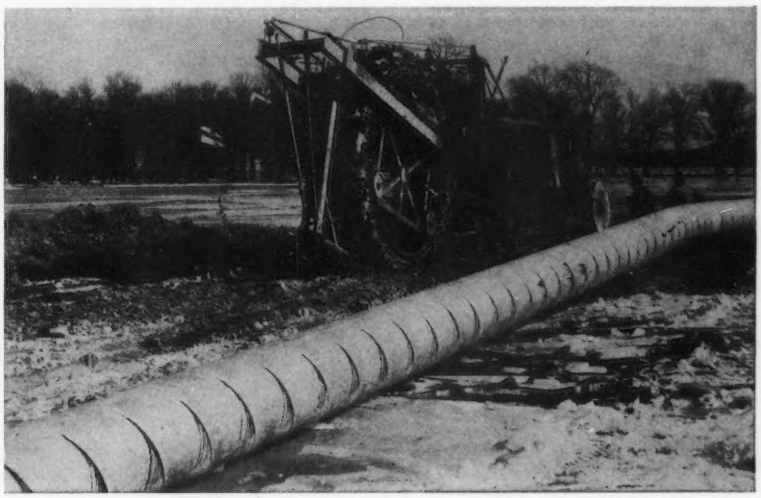
Chemical reactions occurring in a high vacuum at high temp. are grouped into three classes: (1) those in which gases are produced, (2) those in which gases are removed, and (3) those in which one gas is removed and another produced. Reactions considered under (1) and (2) are the oxygen equilibrium over oxide and metal, the formation or removal of carbon monoxide or carbon dioxide by reaction of surface oxides with carbon in the metal, and the vaporization of the metal. Under (3) the reactions considered are the reduction of water to form oxide and hydrogen, the reduction of carbon dioxide to form oxide and carbon monoxide, and the reaction of hydrogen with carbon in the metal to form methane. Apparatus is described for studying these reactions at temperatures up to 1200° C. and pressures of 10^{-5} mm. mercury or less. Results are given for the following reactions: the vacuum oxidation of zirconium, tungsten, molybdenum and stainless steel; the formation of carbon monoxide in the case of stainless steel; the voltalization of molybdenum trioxide; and the oxidation and evaporation of magnesium.—MA.

Influence of Residual Stress on Chemical Behaviour. U. R. EVANS. *Inst. Metals.* Symposium on Internal Stresses in Metals and Alloys, 291-310 (1948); discussion, 463-484.

The transfer of oxide films from nickel to a vaseline basis indicates that a state of constraint must have existed during attachment to the metal. The thicker films show wrinkles, suggesting uniform stress due to misfit between the vol. occupied by oxide and metal; the thinner films curl into rolls, suggesting a stress gradient, probably inherited from surface stresses in the metal. The effect of residual stresses on the distribution of attack in salt solution appears to be connected with film breakdown; the accelerated attack by acid is best attributed to changes within the metal itself. Stress-corrosion cracking is usually connected with electrical currents passing between the tip of the advancing fissure as anode, and a large cathode, generally situated outside the crack. This form of attack (usually intergranular) is shown by materials in a critical condition exposed to liquid of critical composition, capable of producing attack only at the most susceptible places. Corrosion-fatigue cracking (usually transgranular) can occur on almost any material exposed to a corrosive liquid under conditions of alternating stress. Thermal stress relief, carried out under controlled conditions, frequently prevents breakdown under corrosive conditions; if applied without control it may make matters worse. Compressional surface stresses, applied by peening, greatly reduce susceptibility to corrosion-fatigue, and would probably be beneficial in preventing stress-corrosion cracking where this is caused by tensional residual stresses; where the responsible stresses are compressional, it would presumably make matters worse. Paints richly pigmented with metallic zinc offer promise in preventing corrosion-fatigue, and probably corrosion cracking due to internal stresses; they have, however, their limitations. —MA.

Studies of Metal Surfaces by Low-Temperature Gas Adsorption. PAUL H. EMMETT. Pittsburgh International Conference on Surface Reactions. *Proceedings*, 82-90 (1948).

It is possible to obtain a reliable estimate of the absolute surface area of a solid by measuring the low-temp. ad-



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sorption isotherms of suitable inert gases, such as nitrogen, near the boiling point of the gas. Estimates made by two methods using different assumptions do not usually differ by more than 10%, and the values are confirmed by electron micrographs and other methods. Different gases can be used for materials having different total surface areas, examples being argon, oxygen, nitrogen, carbon monoxide, carbon dioxide, butane, krypton, methane, ethylene, and ethane. Examples are given of the use of the method, including the determination of the surface roughness of electrodeposited metals. The usefulness of the knowledge of surface roughness and true surface areas in corrosion studies is emphasized.—MA.

Recent Research on Very Pure Aluminum. (In French.) G. CHAUDRON. *Helv. Chim. Acta*, **31**, 1553-1570 (1948) Oct. 15.

Electrolytically purified aluminum (99.998%) was investigated in relation to passivity to HCl, preparation of the surface, kinetics of the oxidation of exposed aluminum, effects of corrosion, structure, and recrystallization. 27 ref. —BLR.

Electronic Sleuth Seeks Metals' Secrets. *Business Week*, 997 (1948) Oct. 9.

Studies of metallic surface layers less than a quarter-millionth of an inch thick are valuable in determining crystal structure or degree of corrosion, in developing long-wearing metals, and in metallurgical work. Photograph and description of device, called an "electron diffraction instrument." Mfd. by General Electric Co.—INCO.

The "Wetting Effect" Strongly Affecting the Tensile Strength of Solids; "Liquo-Striction" a New Effect Resulting. CARL BENEDICKS. Pittsburgh International Conference on Surface Reactions. *Proceedings*, 196-201 (1948).

In the presence of a wetting liquid the strength of a solid body subjected to cracking may be considerably altered. This "wetting effect" may either strengthen or weaken the material, and it applies to materials such as glass, as well as to metals. Thus, steel and glass were weakened by amounts up to 60% in the presence of water and strengthened by amounts up to 30% in the presence of various organic liquids. This "wetting effect" is important in corrosion-fatigue, caustic embrittlement, season-cracking, and soldering brittleness. Theoretical considerations indicate that the effect is connected with surface tension and surplus attracting forces in the surface. It is predicted that the presence of a liquid will cause a change in dimensions of a solid body—a new effect termed "liquo-striction." This effect is demonstrated by showing that threads of quartz or platinum increase in length when immersed in a liquid. The magnitude of both the "wetting effect" and the "liquo-striction" effect depend on the surface tension of the wetting liquid.—MA.

Influence of the Condition of Iron and Copper on Oxidation at High Temperatures. JACQUES BENARD. Pittsburgh International Conference on Surface Reactions. *Proceedings*, 167-172 (1948).

The results of a number of experiments on the rate of oxidation of copper at 900° C. and of iron at 850° C. are given. The amount of oxidation in a given time decreases as the initial surface roughness is increased. The oxidation rate is also affected by the type of oxide film initially present, so that the whole oxidation process is dependent on the original physical and chemical condition of the surface. Cold working the metal causes it to oxidize more rapidly, and this effect persists even if the metal is annealed after the cold working. In the case of copper it was possible to correlate the structure of the oxide film formed with the degree of cold-working of the metal, and this change in structure is believed to account for the differing oxidation rates. It is confirmed, by experiments with single crystals of copper and iron, that different crystal faces oxidize at different rates. During the initial stages of the oxidation of iron, a short period where the growth curve was linear was observed.—MA.

Inter- and Trans-Crystalline Corrosion and Its Causes. (In German.) F. C. ALTHOF. *Z. Metallkunde*, **36**, No. 8, 177-186 (1944) Aug. Part I; *Metallforschung*, **2**, No. 11, 321-331 (1947) Nov. Part II.

Study of the process of failure of various brasses (55-86% copper), and other alloys in mercury nitrate, ammoniacal atmospheres, caustic soda artificial seawater, ammoniacal water. Specimens were of loop and fork type so that corrosion with and without stress could be compared. Nature and causes of inter- and trans-crystalline corrosion are discussed. It was shown that corrosion in ammonia depends largely on the formation of complex compounds and that the tendency to the above types of corrosion depends on copper contents and stresses. Results indicate that such corrosion is caused by interatomic reactions. 50 ref.

GENERAL

Punched Cards for Filing Corrosion Test Results. LORRAINE R. VOIGT. *Corrosion*, **4**, 582-589 (1948) Dec.

Describes use of Keysort cards for the above by International Nickel Co.—BLR.

Prevention of Deterioration of Metals. U. S. Deterioration Prevention Committee, Minutes, 12th Meeting, 6 p. (1947); *Prev. Det. Abs.*, **4**, Met. 31 (1948).

The subject was discussed under the headings: 1) environment, 2) design, 3) coatings, 4) cathodic protection, 5) metal composition, 6) heat-treatment, and 7) methods of testing.—RPI.

Corrosion of Metals with Oxygen Depolarization. N. D. TOMASHOV. *Light Metals*, **11**, No. 121, 104-112 (1948); No. 122, 155-160 (1948).

Graphical methods for the computation and interpretation of corrosion phenomena are discussed, and experimental methods described for determining cathodic-polarization curves for various materials. Curves for aluminum, Duralumin, various steels, iron, zinc, and cadmium are given. Aluminum and Duralumin are described as being of low cathodic efficiency.—MA.

Corrosion of Metals with Oxygen Depolarization. N. D. TOMASHOV. *Light Metals*, **11**, No. 126, No. 128, 388-396, 503-509 (1948) July, Sept.

These two articles conclude this series (a condensed version of Tomashov's book), which has been in progress since December, 1947. Some peculiarities in the corrosion-mechanism of aluminum and its alloys are discussed in the July installment. In conclusion the author considers the application of polarization curves to the study of problems in the corrosion of metals in practice.—BNF.

Mechanism of Corrosion of Copper-Containing Steels. (In Russian.) N. D. TOMASHOV, G. P. SINEL'SHCHIKOVA AND M. A. VEDENEEVA, Doklady Akad. *Nauk USSR* (Reports of the Academy of Sciences of the USSR), **62**, 105-108 (1948) Sept. 1.

Critically analyzes various theories concerning the corrosion resistance of steels containing 0.2-1.0% Cu. It is believed that the increased corrosion resistance of such steels is caused by deposition of finely dispersed copper, which promotes, under certain conditions, anodic passivity of iron. Experimental results seem to confirm this hypothesis. 12 ref.—BLR.

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Iron and Steel. (In 1947.) G. E. SPEIGHT. Soc. Chem. Ind., *Reports on the Progress of Applied Chemistry*, **32**, 72-90 (1947) (pub. 1948).

Survey based on 116 references, under the headings: mineral resources and treatment of iron ores; production of pig iron and ferro-alloys; foundry practice; direct production processes for iron; production of steel; analysis; properties and tests; corrosion; surface treatment; heat treatment, metallography, welding.—BNF.

Causes of Steel Corrosion. I. RICHARDS. *Org. Fin.*, **9**, No. 8, 41-6 (1948) Aug.

Factors discussed influencing corrosion include the presence of warm outside air adjacent to a surface with a cold inside temperature tending to induce surface condensation, as in the case of refrigerators, or exposure to corrosive gases and dampness. Under normal conditions, the application of an organic coating of paint is sufficient to function as a protection for exposed iron and steel. Chemical considerations of corrosion and theories of corrosion, in particular the present accepted electrolytic theory, are discussed in simplified form.

The Electrical Engineer's Responsibility for Recognizing Corrosion as a Factor in the Design of Electrical Structures. M. C. MILLER. Ebasco Services, Inc., New York, N. Y. *Corrosion*, **3**, No. 7, 341-346 (1947) July.

Many electrical structures have been designed which are actually conducive to corrosion. Since most corrosion is a result of either electrolysis or galvanic corrosion in soils or in the atmosphere, the electrical engineer should be especially conscious of his role in reducing corrosion.

The simple-cell action of dissimilar metals in soils and aqueous solutions is often overlooked in designing. Corrosion from electrolysis or stray man-made current, such as d-c railway current, can cause extensive failures in lead cable sheaths and pipelines within 2-3 yr., or occasionally within a few months. Many failures of lead-covered cables are the result of corrosion caused by the extensive use of copperweld ground rods and copper grounding cables at generating stations, and from the use of bare copper neutral cable in duct lines. It is general practice to install copper ground rods in manholes, adding to the corrosion factors. Where lead-covered cables are subjected to electrolysis from stray street-railway current, the use of copper or copperweld ground wires is especially detrimental. Zinc or magnesium anodes, from the point of view of current pick-up and discharge, would be desirable, although there are some limitations to their use for electrical grounds.

Electrical systems are frequently grounded to water systems which, in turn, are connected to gas systems and other buried metallic structures. Although lead sheath is close in potential to steel and cast iron pipes, under some soil and duct conditions it may be quite anodic to them. This effect due to differences in potential is much more serious when brass and copper pipes are used for gas and water services.

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differences in potential. Corrosion problems which are encountered around a steam plant are also pointed out.—DPA.

Great Interest in Corrosion Engineering. *Marine Eng. and Shipping R.*, **53**, No. 10, 62 (1948) Oct.

An exceptional growth of a non-profit technical association to meet a specialized need is that of the National Association of Corrosion Engineers. The association was started in 1944 by only a dozen pipe line engineers who sought to do something about the enormous loss industry is suffering through corrosion. In 4½ years it has grown to include more than 1,400 active members and 190 company members. The active members include principally engineers working on corrosion problems employed by companies in 32 industries, by various federal, state and municipal agencies, and by the military services, universities and engineering consultants. The company members include corporations in 18 industries, with such representative ones as Bell Telephone System, Alcoa and International Nickel, General Electric and Westinghouse, and many others. The managements of these corporations recognize the fact that the economic losses of corrosion include not only the immediate plant repairs or renewals but also corrosion-caused production or service interruptions, commodity losses or spoilage, curtailed revenues, accidents, fires, personal injuries or deaths, public property damage, customer and public inconvenience, and employee, customer and public ill-will. To avoid duplication, the NACE has accepted responsibility for carrying on the functions of the war-born American Co-ordinating Committee on Corrosion, now called the Inter-Society Corrosion Committee. It will have a member from each of a number of societies and associations working on corrosion problems. The association has been campaigning to extend to other industries its memberships on the premise that solving corrosion problems requires the pooling of experience as well as conduct of research. NACE is governed by officers and directors elected by the members. This year's president is F. L. LaQue of the International Nickel Company.—ALL.

American Society of Heating and Ventilating Engineers 1948 Research Program Includes Study of Corrosion. *Heat, Piping Air Cond.*, **20**, No. 4, 144-145 (1948) Apr.

Among projects under study and development by Technical Advisory Committees of the A.S.H.V.E. is the study of water-formed deposits and corrosion in heating and air conditioning equipment. Names of men on research committee are listed.—INCO.

The Resistance of Aluminum Alloys to Corrosion. E. H. Dix, Jr. and R. H. Brown. *Metals Handbook, Amer. So. Metals*, 791-797 (1948).

A concise review, covering the corrosion behavior of aluminum and its alloys (including contacts with dissimilar metals, the electrode potentials of alloy constituents, and the effect of heat-treatment); the relative resistance to corrosion of the various commercial alloys, both cast and wrought; resistance to atmospheric exposure; resistance to waters; aluminum alloys for chemical plant and equipment (with notes on the behavior towards various classes of chemicals and typical applications); and aluminum for preparing and processing food. 19 references are given.—MA.

Prevention of Iron and Steel Corrosion: Processes and Published Specifications. C. Dinsdale. Demy 8vo. 67p. (1948). Lond. Iliffe and Sons, Ltd. (5s.).

It is necessary to quote the sub-title of this book, "Processes and Published Specifications," as well as the title in order that the contents be adequately described. It consists essentially of a series of tables listing processes available for protecting iron and steel from corrosion, and specifications which have been issued regarding such processes. The contents are divided into three parts, dealing with methods of preventing corrosion, cleaning of metals, and codes of practice. The first part includes, in 11 sections, details of metallic coatings, organic and inorganic coatings, electrolytic methods, and water treatment. There is an appendix dealing with specifications relating to paints and paint compounds. Throughout, specifications from many countries besides Britain and the U.S.A. are included in the tables.

As well as standard techniques, proprietary processes have been listed, and it seems inevitable that omissions will have been made. No doubt these will be brought to the author's notice. Brief introductions to each section are given, and some of these could have been profitably expanded. For instance, it is hardly possible to deal adequately with the subject of metallic coatings on steel in 10 lines.

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engineers and others who are concerned with the preservation of machinery. It should be especially useful to those who have to advise on the protection of iron and steel against corrosion in all sorts of environments. The book is well produced and the price is very reasonable. —MA.

Stainless Steels and Other Ferrous Alloys. M. H. BROWN AND W. B. DELONG, duPont de Nemours & Co., *Ind. Eng. Chem.*, 40, No. 10, 1812-1820 (1948) Oct.

Literature review of stainless steels and other ferrous alloys as to passivity and corrosion resistance structure and mechanical properties, high temperature corrosion and properties, and welding. High silicon-iron, nickel-iron alloys and austenitic manganese steels are covered. Bibliography of 232 references.—INCO.

Magnesium and Its Light Alloys. (In French.) **(Le Magnesium et les Alliages Ultra-Legers).** P. BASTIEN. 104p. (1948). Dunod, 92 Rue Bonaparte, Paris. Paper-covered 360fr. From British booksellers, 9s. 6d.

This is a concise introduction to the metallurgy of magnesium, covering a wide range of topics, including extraction and purification; properties of magnesium; some binary and ternary diagrams; alloy formation from the atomic point of view; casting; jointing; corrosion and protection. As might be expected from Professor Bastien, the chapter on casting is long and detailed. Short select bibliographies on various topics are provided.—BNF.

The Resistance of Copper and Wrought Copper Alloys to Corrosion. Amer. Soc. Metals, Sub-Committee on Corrosion of Copper. *Metals Handbook, Amer. Soc. Metals,* 895-899 (1948).

The various types and causes of corrosion are described, the effect of alloy composition is discussed, and the corrosion ratings of the common alloys in a variety of media are tabulated. There are also some notes on protective coatings and the selection of suitable alloys for particular purposes.—MA.

INHIBITORS

A Simple Test Method for Evaluating Corrosion Inhibitors. J. W. RYZNAR AND J. GREENE, Nat. Aluminate Corp. *Corrosion,* 4, 505-515 (1948) Nov.

A description is given of a simple, rapid reliable laboratory test for screening possible corrosion inhibitors and for evaluating those materials which are found to be effective. The main purposes of the test are (1) to determine whether a substance will or will not inhibit corrosion sufficiently to be of practical importance, (2) to determine significant differences in the effectiveness of inhibitors or between different concentrations of the same inhibitor, and (3) to determine the effectiveness of a given inhibitor under a variety of environmental conditions. A solid metal cylinder is rotated at a constant speed by means of a motor for 24 hr. in water containing the inhibitor to be tested. A solid cylindrical specimen approx. 0.25 in. in diam. and approx. 3 in. long is prepared from quarter-inch round, hot-rolled SAE 1020 mild steel. The water used in routine tests consists of Chicago tap water and distilled water in equal volumes to which sodium chloride is added. The test water is contained in a Pyrex beaker, supported on an electric heater. The volume of water is kept constant by a float valve arrangement which automatically maintains the original water level through the admission of distilled water from a reservoir. The potential of the specimen is measured relative to a one-normal calomel half-cell. In carrying out a test, the specimen is inserted in an insulated holder and mounted in the chuck of the motor, immersed to a depth of 1 in. of water and rotated at constant speed for 24 hr. After the specimen has been dried, results are evaluated on the basis of visual observations. The advantages of this method are its short duration, easy evaluation, and precision. 13 illus.—TDD.

Evaluation of Pickling Inhibitors from the Standpoint of Hydrogen Embrittlement. I. Acid Pickling of Stainless Steel. II. Acid Pickling of Carbon Steel. C. A. ZAPFFE AND M. E. HASLEM. *Wire and Wire Prod.,* **23,** No. 10, No. 11, 933-935, 1048-1055, 1080-1082 (1948) Oct. Nov.

Commercial pickling inhibitors are compared from the standpoint of hydrogen embrittlement incurred during the pickling of stainless steel in sulphuric acid by means of a bend test on the wire. Deals with the pickling of mild steel in sulfuric acid. 15 reagents were studied, including 13 of the more widely used commercial inhibitors, one inhibitor base, and one reagent specially

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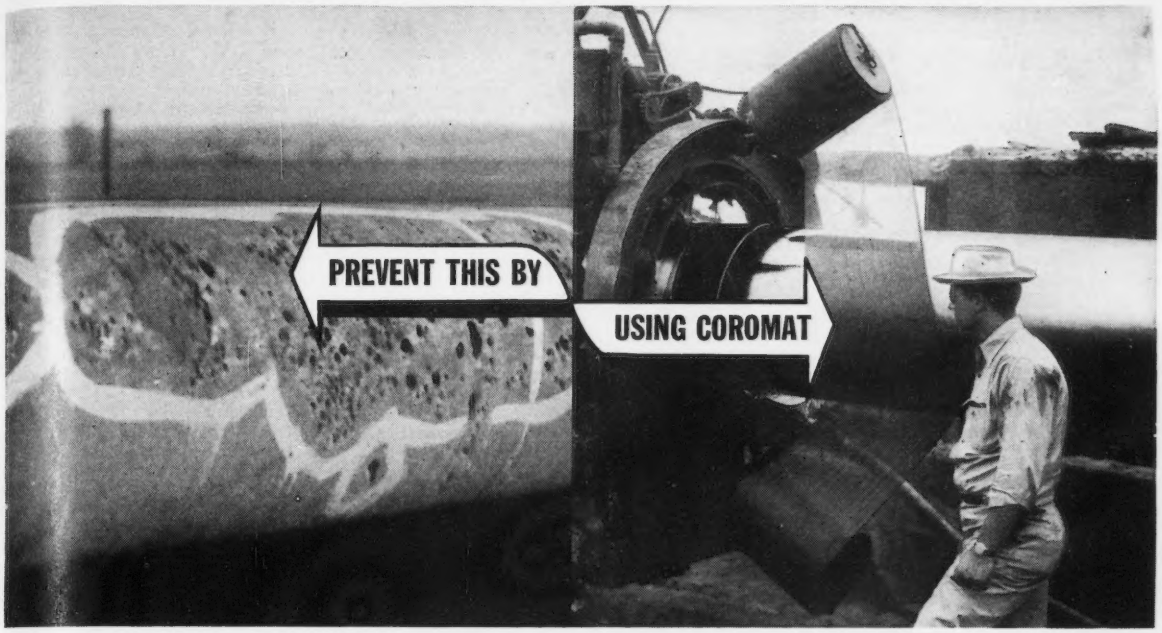

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designed to prevent embrittlement. Seven of the reagents studied failed to prevent embrittlement regardless of concentration; four others failed to prevent embrittlement within their proprietary ranges, and four satisfactorily prevented embrittlement throughout their proprietary ranges. Of the latter four inhibitors, only the specially designed reagent represses embrittlement during pickling of stainless steel. Some theoretical problems are discussed. Part III, which will appear in the December, 1948, issue deals with cathodic pickling.

Corrosion Inhibitors. A. G. SUSSEX. *Australasian Engr.*, 1947, 68-75; *Chem. Abs.* **42,** No. 15, 5401 (1948).

A review of the mechanism of corrosion inhibition, which views this essentially as polarization of anodic or cathodic areas by the inhibiting substance. Various systems are discussed, and an outline of exptl. methods is given. Vapor-phase inhibitors are mentioned and specifically morpholine nitrite and 2-amino-butane nitrite. The following topics are touched on: the effect of arsenic in repressing dezincification of brass, surface-active substances as corrosion inhibitors and undesirable effects arising from their use, and the nature of the surface film formed on iron which has been inhibited by chromates. 28 ref.—RPI.

Corrosion Control with Calgon. O. RICE. *J. Am. Water Works Assoc.*, **39,** 552-60 (1947) June; *Public Health Eng. Abs.*, **28,** No. 5, 43 (1948) May.

Information and charts are presented on the effects of the use of glassy phosphate for corrosion control, prevention of precipitation of dissolved iron and manganese from well water, and against tuberculation. As little as 1 to 2 p.p.m. of metaphosphate is effective in reducing corrosion. The amount required for iron stabilization is 2 parts phosphate for each part of iron in water. The use of phosphate glass against tuberculation may be the most important application. (No more information in abstract.).

Wasserglas als Korrosionsschutz Gegen den Angriff von Soda auf Aluminium. (Protective Effect of Water Glass Against the Corrosive Action of Soda on Aluminum.) GELLER, Vereinigte Aluminium-Werke, A.G., Lautawerk, Ger. Office of Technical Services, PB-70016 Frames 6609-6610 (1937) July.

The concentration of water glass necessary to protect aluminum from corrosive attack in sodium carbonate solution is not proportional to the concentration of the carbonate present; larger quantities of the water glass are required at lower carbonate concentrations.

Aluminum sheets of 99.5% purity were immersed in a 10% solution of sodium carbonate, both alone and with additions of 0.05, 0.1, and 0.2% water glass. Dilutions of 1:10 and 1:100 of the various mixtures were also tested. Weight losses were determined on 1-mm thick sheets after 48 hrs. in the liquids. In the undiluted sodium carbonate solution, 0.05% water glass completely prevented any weight loss but in the 1:100 solution even 0.2% did not retard corrosion. In the 1:10 dilution, however, 0.2% was effective. Weight losses in the samples were accompanied by a coating of a thick, yellowish brown oxide film. These results are of interest in connection with cleaning compositions containing solid sodium carbonate and water glass.—DPA.

Sinclair Rust Inhibitor. *Machinery*, 55, No. 2, 232 (1948) Oct.

RD-119, a rust inhibitor for gasoline and fuel-oil lines. Mfd. by Sinclair Refining Co.—INCO.

Topics — Salt-Sodium Dichromate. *Mach. Des.*, **20,** No. 10, 82 (1948) Oct.

Salt-sodium dichromate solution, in place of salt usually used for snow and ice removal on municipal streets, has reduced corrosion of auto fenders and bodies at joints, in a test program carried out by Goodyear Tire and Rubber Co.—INCO.

Some European Researches on Passivity. U. R. EVANS. *Corrosion*, 4, 545-556 (1948) Nov.

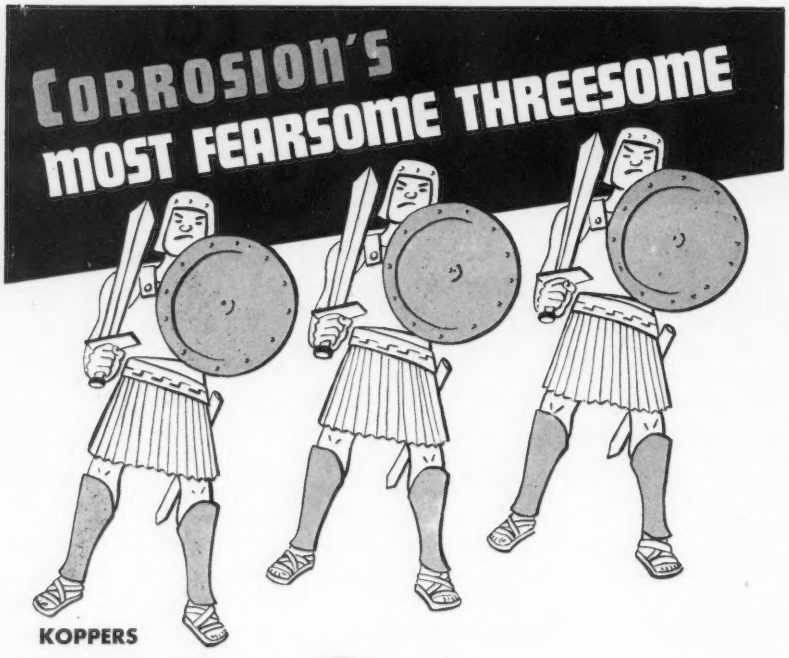
Critically reviews the above. 57 ref.—BLR.

Some Notes on the Uses and Effects of Inhibitors in the Acid Pickling of Iron and Steel. P. DE LATTRE. *Sheet Metal Ind.*, **25,** Nos. 258, 259, 1961-1964, 2181-2188 (1948) Oct., Nov.

Aims at providing a review of the present position, taking into account the classical theory of the dissolution of metals in acid solutions. Contains a comprehensive bibliography, including many patents.—BNF.

Chromate Corrosion Inhibitors in Air Conditioning Waters. M. DARRIN. *Public Works*, **78,** 27-8 (1947) June; *Public Health Eng. Abs.*, **28,** No. 5, 44 (1948) May.

The use of chromate and bichromate



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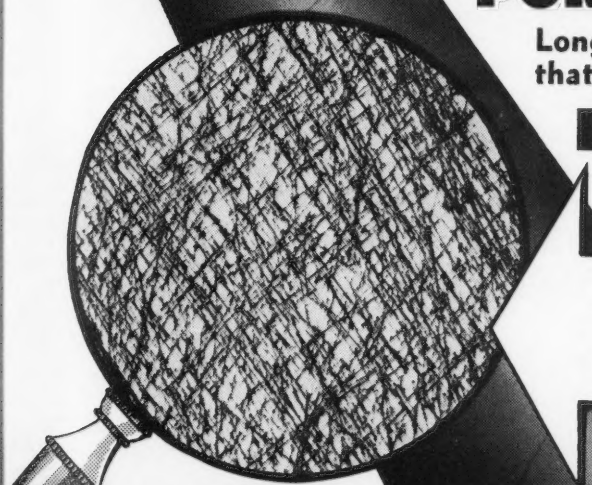

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to inhibit rust, sediment and slime in recirculating systems is reviewed. A small amount of chromate or bichromate (approximately 250 p.p.m.) is needed to control corrosion. A passivating film is created on the exposed surface of the metal, and reducing substances in raw water are oxidized by the use of chromate. Also presented are details relating to environmental factors, concentrations, specific applications and bimetallic corrosion. (No more information in abstract.)

Use of Wetting Agents in Conjunction with Acid Inhibitors. P. H. CARDWELL AND L. H. EILERS. *Ind. Eng. Chem.*, **40**, No. 10, 1951-1956 (1948) Oct.

The presence of wetting agents in acid solutions containing organic inhibitors (thiourea and nitrogen-ring compounds) reduced the amount of corrosion of a metal to an extent which seems to depend upon the initial degree of wetting of the metal by the aqueous acid-organic inhibitor solution. This work is in agreement with the theory that the cross-sectional area of an adsorbed organic molecule as projeced on to a metal surface is one of the factors that determine the value of the material as a corrosion inhibitor. The wetting agents do not inhibit corrosion when used alone with hydrochloric acid. 20 ref.

Corrosion of Boiler Steels by Inhibited Hydrochloric Acid. P. H. CARDWELL AND S. J. MARTINEZ, Dowell, Inc. *Ind. Eng. Chem.*, **40**, No. 10, 1956-1964 (1948) Oct.

The corrodibility of steels used in boiler construction was determined at various temperatures in inhibited hydrochloric acid solutions (10% at 150 and 175° F.). The effectiveness of four acid inhibitors and the method of preparing test coupons were studied. Considerable variation in the corrodibility of the steels were attributed in part to their carbon and silica contents. One of the inhibitors was dibutylthiourea, composition of the others only partly known. Metals used in boiler construction should be annealed or possibly normalized to have low corrodibility.

The Use of Inhibitors for Controlling Metal Corrosion. Part I—General Principles. G. T. COLEGATE. *Metallurgia*, **39**, No. 229, 18-20 (1948) Nov.

In this first article of a series author deals with types of corrosion and classifies the various inhibitors in use into groups.—BNF.

Corrosion-Inhibitor Applied to Paper. *Chem. Eng. News*, **26**, No. 44, 3302 (1948) Nov. 1.

The Shell Development Co. has developed a vapor phase rust inhibitor in the form of a treated wrapping paper. The compound, a synthetic organic material, is inert toward both oxygen and water. The molecule is polar and produces a passive state on the surface of all ferrous metals and aluminum alloys which persists for several hours after exposure to the vapors. The pure inhibitor is a water-soluble, white crystalline material which is applied to paper as an aqueous paste during the finishing operations. When treated paper is used to wrap metal parts the inhibitor produces a non-reactive atmosphere around the part which will persist for as long as several years in a confined space. Ferrous or aluminum alloys may also be immersed in very dilute solutions of the inhibitor to prevent corrosion.—ALL.

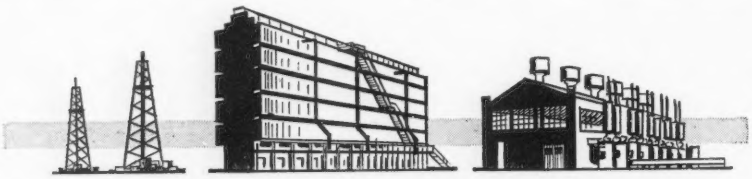
Polar-Type Rust Inhibitors; Theory and Properties. H. R. BAKER AND W. A. ZISMAN. *Ind. Eng. Chem.*, **40**, 2338-2347 (1948) Dec.

The various physical and chemical phenomena which are involved in the adsorption of polar solutes from nonpolar or weakly polar solvents are discussed. The mechanism of the rust inhibition is analyzed. The rust inhibition obtainable in a reference petroleum oil by the addition of a variety of polar compounds was observed using the turbine-oil rusting test at different concentrations and temperatures. Results are classified and interpreted. Conclusions are generalized by comparison of data obtained for selected polar compounds dissolved in petroleum oils, pure hydrocarbons, chlorinated hydrocarbons, aliphatic diesters, polyalkylene glycol derivatives, and silicone fluids. 30 ref.—BLR.

INSPECTION

A Mechanical Test for Detecting Longitudinal Fissures in Fine Wire. D. W. WHITE. *Metal Prog.*, 54, 837-841 (1948) Dec.

Describes test, designated the "knife-edge" test, which determines the ability of a wire to withstand tension over a relatively sharp knife edge of known radius of curvature while being rotated about its longitudinal axis. Straining the specimen in this way will cause fracture of a wire having flaws. The test is being used for quality-control inspection of



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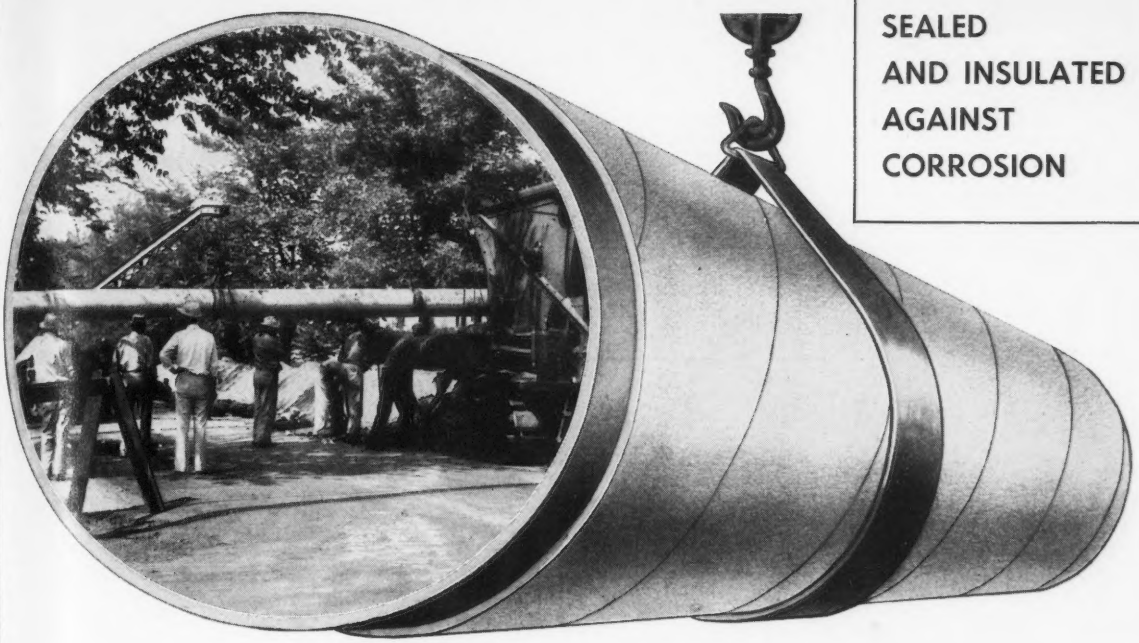

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semifinished tungsten wire for lamp filaments. Suggests possible application to other kinds of wire.—BLR.

Profitable Mass X-Ray Inspection. JUSTIN G. SCHNEEMAN. *Non-Destructive Test.*, **6**, No. 4, 25-29 (1948).

Attention is directed to those aspects of industrial radiography and fluoroscopy which lead to less costly and more efficient inspection. It is concluded that profitable X-ray inspection can be achieved by: (a) selection of the most economical method of inspection, e.g. fluoroscopy, radiography with X-rays or radium; (b) accurate film-processing procedure; (c) unbiased and practical interpretation of the radiographic results; (d) minimum use and spoilage of X-ray film; (e) 100% inspection of all vital processes or parts, possibly combining fluoroscopy and radiography; (f) careful choice of operators; and (g) inspection in the minimum amount of time, while maintaining top quality.—MA.

The Analysis of Industrial Problems Coordinated Spectroscopy and X-Ray Diffraction. W. J. POEHLMANAND AND W. A. KLUCK. *Non-Destructive Test.*, **7**, No. 1, 19-22 (1948) Summer.

While spectroscopy or X-ray diffraction in itself may yield significant information, a more complete knowledge of many variables can be obtained by a coordinated analysis. The complete analysis thus includes a quantitative measurement of major, minor and residual elements, an identification of the important compounds or metallurgical phases, and information concerning the particle size, presence of strain, extent of solid solution, and the degree of preferred orientation present. Numerous examples of typical problems are discussed showing the application of spectroscopy, X-ray diffraction, and the combination of both methods.—ALL.

New Thickness Gage Increases Sheet Output. *Iron Steel Eng.*, **25**, No. 2, 153, 155 (1948) Feb.

For high-speed rolling mills, X-ray thickness gage offers no contact with material being gaged, access to areas never before gaged, high sensitivity and accuracy, increases output of prime sheet, solves operating problems, eliminates marring of materials gaged and is unaffected by fluttering of sheet, surface coatings or atmosphere. Used in thickness control of hot metal and glass sheet, aluminum foil, plastics, paper and sheet and strip materials. Mfd. by Westinghouse Electric Co.—INCO.

The Supersonic Reflectoscope, an Instrument for Non-Destructive Testing and Measuring by Means of Sound Waves. *Iron Age*, **162**, No. 19, 113 (1948) Nov.

The Reflectoscope was the subject of a lecture delivered by Dr. F. A. Firestone to the Society for Non-Destructive Testing in conjunction with the National Metal Congress. Dr. Firestone dealt primarily with unusual uses of the instrument developed in the laboratory which in the future should prove valuable in industry. One of the most interesting of these is the determination of average grain size in metals by the study of the pattern caused by wave reflection of grains of large size in respect to wave length. By choosing the proper wave length, i.e., lengthening wave length for larger grains, any size grains can be determined. In effect, relatively large grains diffuse the waves and show up as small flaws would in ordinary inspection work.

The use of shear type waves for measurement of Young's modulus, the modulus of elasticity and Poisson's ratio was described, and methods using combined rocking-shearing waves for surface testing and measurement by sending waves, much like waves of water, along the sample surface, with penetration adjusted by wave length, were reviewed. The shear and other type waves move more slowly through the metal samples than longitudinal waves, but the individual properties of these waves provide the key in techniques not possible with the longitudinal type.

An instrument designated the Raybender, which has been built and used only in the laboratory to permit testing of spots inaccessible to the beams of a standard instrument, was described. In the unit, the quartz crystal is contained in a mercury chamber somewhat removed from the specimen surface. The crystal is angled to the specimen and rays, transmitted by the mercury, hit the sample and are deflected to the spots to be reached.

A quick test using shear waves for determining directional differences in the shearing moduli of cold-rolled metals was described and it was reported that differences up to 10 per cent in the same samples, according to direction of roll, have been found.—ALL.

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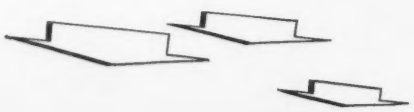

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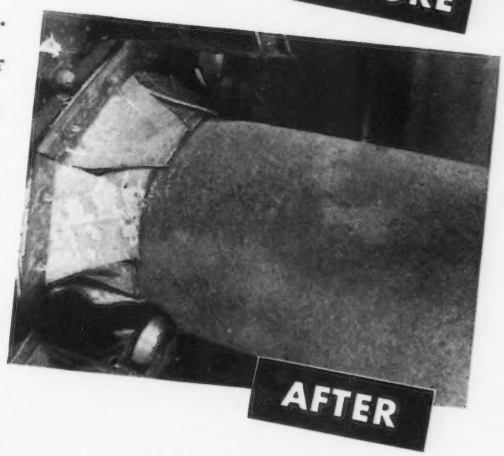

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A Portable Ultrasonic Thickness Gauge (Audigage). DWIGHT J. EVANS. *Non-Destructive Test.*, **6,** No. 4, 22-24 (1948).

The instrument uses a quartz-crystal vibrator fed by a variable-frequency power supply. The crystal is placed on the specimen and the frequency adjusted until the object vibrates in resonance as indicated by a signal in head-phones. This frequency is related to the specimen thickness by equations which are given. The instrument (known as the Audigage) gives direct readings of metal thicknesses for steel specimens and operates over a thickness range of ½ to 12 in. Details are given of the limitations and accuracy.—MA.

Electrographic Printing of Pores in Protective Coatings. Allen G. Gray. *Products Finishing,* **12,** No. 5, 62, 64 (1948).

The method involves anodic solution of the metal underlying the protective coating, transmission of the cation through the pores in the film, and retention of the metal ions on a paper in contact with the film and the coating. The paper is subsequently developed in a suitable solution, resulting in the formation of a colored metal salt which indicates the location and approximate size of the pores and cracks in the coating. For determining the porosity of coatings on ferrous metals the paper is soaked in 5% potassium nitrate for 30 minutes and excess solution squeezed out under a press. This paper is laid on the surface to be tested and a piece of blotting paper similarly treated laid over it, followed by the cathode platen, and the whole assembly placed in a press. The current is switched on for 20 sec. and the paper removed and developed in a bath containing 25 g./l. of potassium ferrocyanide and 25 g./l. of potassium ferricyanide in distilled water. 30 minute immersion in this bath is sufficient, and the paper is then removed, washed free from the yellow color of the ferricyanide, and dried, leaving a record of the position and number of the pores in the coating.—MA.

Castings Industry Applications of Magnetic-Particle Inspection. W. E. Thomas. *Trans. Amer. Found. Assoc.,* **55,** 482-488 (1947); discussion, 489.

Developments in the application of magnetic-flux methods for the non-destructive examination of cast products are reviewed.—MA.

Non-Destructive Testing and Its Place in the Current and Prospective Navy Programs. R. H. Lambert. *Non-Destructive Testing,* **7,** 20-21 (1948) Fall.

Briefly discusses the above.—BLR.

Metallographic Examination of Surface Films by Oblique Sectioning. H. Klemm. *Metall.,* **1947,** Nos. 5/6, 79-83.

The technique, applications, and advantages of oblique sectioning for the microscopic examination and measurement of the thickness of surface films and coatings are described and illustrated.—MA.

Sensitivity and Exposure Graphs for Radium Radiography. H. E. Johns and C. Garrett. *Canad. J. Research,* (A), **26,** No. 5, 292-305 (1948).

The authors used a slotted-steel wedge penetrameter to determine differential-sensitivity curves for a number of common X-ray films exposed to gamma radiation. The thickness of lead front screen giving the maximum intensifying effect was also determined; this thickness is not necessarily the most useful thickness for gamma radiography. The optimum screen thickness may be determined from the sensitivity curves. The importance of these curves in routine testing is discussed.—MA.

Supersonics versus Radiography. Herbert R. Isenburger. *Metal Progress,* **54,** No. 3, 318-319 (1948).

Supersonic examination gives only an indication of the presence of a defect; it must be supplemented by radiography if the true extent and character of the defect are to be determined. I. exemplifies this by reference to some tests of his own on welds in pressure vessels.—MA.

Castings Industry Applications of Magnetic-Particle Inspection. W. E. Thomas. *Trans. Amer. Found. Assoc.* **55,** 482-488 (1947); discussion, 489.

Developments in the application of magnetic-flux methods for the non-destructive examination of cast products are reviewed.—MA.

Radiology of Joints in Welded Piping for Power Plants. E. Thomas. *Proc. Inst. Mech. Eng.,* **158,** No. 1, 1-5 (1948); discussion, 5-8.

Discusses the use of X-ray and gamma-ray equipment for the examination of welded power-plant piping fabricated from copper and plastic.—MA.

Influence of Fine Cracks on the Mechanical Properties of Stainless Chromium Steel. (In Russian.) V. I. Smirnov and N. S. Orlova. *Kotloturbostroenie (Boiler and Turbine Manufacture),* 21-23 (1948) July-Aug.

Results of experiment show that, in the case of coincidence of the direction of fine cracks with the direction of prevailing stresses, the above influence is insignificant. On the contrary, if the directions do not coincide, a considerable decrease in plasticity is observed. Fine cracks do not decrease the corrosion resistance of the above steel in supersaturated steam.—BLR.

The Use of X-Rays in Industry. H. P. Rooksby. Mem. Soc. Roy. *Belge Ing. et Indust.,* (B), **4,** No. 2, 21-41 (1947).

A wide range of radiographic and crystallographic applications is mentioned, including the detection of all kinds of porosity and the mottling due to large grain-size in aluminum alloys, the inspection of steel components, and the cine-radiography of welding operations. Reference is made to X-ray tubes working with 1 million volts, improved back-reflection and powder techniques (including the use of ionization chambers and Geiger counters), the development of the A.S.T.M. catalogue of diffraction-pattern data as an aid to structure identification, and the determination of crystal size, orientation, degree of perfection and changes in composition. Possible lines of progress are discussed. —MA.

Stress-Free Material Testing. F. Rohner. *Schweiz. Arch. angew. Wiss. Techn.,* **14,** No. 10, 289-293 (1948).

A brief review of some non-destructive testing methods: (1) radiography, (2) electrical crack detection, (3) magnetic crack detection, and (4) supersonic testing.—MA.

An Examination of the Thiocyanate Porosity Test for Tinplate. J. Pearson and W. Bullough. *J. Iron Steel Inst.,* **160,** No. 4, 376-380 (1948).

The authors investigated the porosity test originally proposed by Kerr [*J. Soc. Chem. Ind.,* **61,** 181 (1942); *Met. Abs.,* **10,** 214 (1943)] and found that the results obtained were liable to be inaccurate unless certain precautions were taken, notably with regard to the cleaning of the specimens, the preparation of the solutions, and the analytical procedure. The temperature of the test was not found to be critical. The influence of scratches and of total pore area was investigated over the range of coating weights covered by commercial hot-dipped tinplate the test result is proportional to the number of pores. Based on their results the authors recommend a modified procedure for routine porosity testing; it is shown statistically that this procedure has adequate reproducibility. Since other work had shown that the porosity of tinplate is proportional to the thickness of the coating it was to be expected that the thiocyanate-test results, if a true measure of porosity, would vary linearly with coating thickness. A statistical survey of a large number of tests on sheet coated with various thicknesses of tin (15-75 oz. per basis box) indicated that this was in fact the case, the porosity P (mg. iron dissolved per 100 cm.²) being related to the coating weight W (oz. per basis box) by the relation:

$$\log_{10} P = 2.39 - 2.22 \log_{10} W \pm 0.52.$$

This equation applies to good quality commercial hot-dipped material. It is suggested that the equation might be used to assess the effect on the quality of the tinplate of modifications to existing processes, or of the introduction of new processes.—MA.

Electronics in the Field of Non-Destructive Testing. R. Meakin. *Trans. Soc. Instrument Technol.,* **1,** No. 3, 26-35 (1948) Sept.

General principles, and discussion of ultrasonic instruments.—BNF.

Non-Destructive Testing of Drill Pipe. Robert C. McMaster. *Non-Destructive Testing,* **7,** 27-33 (1948) Fall.

Discusses causes of drill-pipe failures, recommended drilling techniques and inspection procedures, typical defects and frequency of their occurrence, and economics of drill-string inspection. 26 references—BLR.

Supersonic Flaw Detectors. DONALD G. ERDMAN. *Elec. Eng.,* **67,** No. 2, 181-185 (1948).

Echo techniques similar to those of sonar and radar are used to locate hidden defects inside solid metal objects. They may be used in conjunction with, and supplementary to, X-ray testing.—MA.

Resonant Frequency as a Means of Inspection. EDWARD EPREMIAN. *Metal Progress,* **54,** No. 1, 64 (1948).

Small assemblies can be clamped at one end in a vise and caused to vibrate at their natural frequency by means of a current of air. If one of a batch of identical assemblies vibrates at a lower frequency than the rest, it is likely to be defective. The frequency is measured by a tachometer, coil magnet, or oscilloscope.—MA.

Ultrasonic Thickness Indicator. BENSON CARLIN. *Electronics*, **21**, 76-79 (1948) Nov.

Describes nondestructive testing and gaging device which gives visual display. Equipment comprises motor-driven variable frequency oscillator, contactor-initiated R-C sweep, crystal transducer, and cathode-ray tube. Graduated screens provide direct readings.—BLR.

Non-Destructive Testing in the Design, Manufacture, and Evaluation of Naval Ordnance. LESLIE W. BALL. *Non-Destructive Test.*, **7**, No. 1, 7-14 (1948).

The principles and practice of nondestructive testing in the design, manufacture, and critical examination under service conditions of naval ordnance are reviewed. Aspects of interest to the metallurgist are: (1) photo-electron radiography, in which the photo-electrons from metal surfaces excited by hard X-rays are recorded on a photographic emulsion laid in contact with the metal, thus revealing differences in the metal structure; (2) the radiographic inspection of aluminum cast around copper tubes; any attack on the copper is revealed in the X-ray image; the attack is inhibited by chromium plating the copper; (3) leaky zinc die-cast projector nose pieces are detected by filling them with a fluorescent fluid and later examining the outer surface of the fuse by ultra-violet light.—MA.

Ultrasonic Materials Tester. *Automotive Ind.*, 99, No. 9, 50 (1948) Nov.

The General Electric Company laboratory at Schenectady, New York, has developed the ultrasonics materials tester which uses high-frequency sound waves to discover and record small flaws in metals. The instrument shoots 1,000,000 cycle-per-second sound waves through the metal to be tested, and simultaneously plots a graph which indicates any flaws in the metals interior. The metal specimen is immersed in oil, and a small transmitter wired to the main body of the instrument sends the sound through the oil and through the specimen. Any flaw in the metal interrupts the sound wave in its path to the receiver. The transmitter is a small crystal made to vibrate and produce sound waves by an electric current. The receiver is a similar crystal, mounted opposite the transmitter and connected to a separate power supply.—ALL.

METAL FAILURE

Vergleichende Korrosionsversuche mit Drei Magnesium-Legierungen (Comparative Corrosion Experiments with Three Magnesium Alloys). NICOLINI, Vereinigte Aluminium-Werke, A.G., Lautawerk, Ger. Office of Technical Services, PB-20019, Frames 12196-12199 (1940) June.

Low alloyed magnesium-manganese samples were less attacked by a sodium chloride-hydrogen peroxide solution than were magnesium-aluminum alloys and a new Giesche alloy containing magnesium plus 5% aluminum, 5% zinc, 4% cadmium, 2% bismuth, and 0.2% manganese. All alloys except the magnesium-manganese group were sometimes heavily corroded within 1 day and their loss in tensile strength and elongation was great. Among the magnesium-aluminum alloys, the Electron type behaved somewhat better than the Magnewin type. Both types, however, were deeply corroded in addition to being changed in their mechanical properties. The Giesche alloy was decomposed more rapidly and more uniformly over the entire surface. Individual samples deviated widely in their resistance to corrosion.

The Electron series included the Mg-Mn, Mg-Al_2, and Mg-Al_4 types and the Magnewin group the Mg-Mn, Mg-Al_2, Mg-Al_4, and Mg-Al_8 alloys. The Giesche alloy was heated for 5 hr. at 330° C. and 4 hr. at 350-355° C., then quenched in an oil-water emulsion of 2-3 parts oil and 1 part water, and annealed for 90 hr. at 150° C. Tables.—DPA.

Alterung und Korrosion der Zamaklegierungen. (Aging and Corrosion of Zamak zinc-aluminum Alloys.) A. BURKHARDT. Metallgesellschaft, A.G., Frankfurt, Ger. Office of Technical Services, PB-70034, Frames 145-196 (1935) April.

Aging and intercrystalline corrosion tests on Zamak 2, 3 and 5 were very different from the results reported in the United States. Zamak 2 and 5 gave essentially better performance in the German tests but Zamak 3 was comparatively poor. Die casts of the Zamak 3 lost 50-60% of their initial impact resistance in a 10-day aging test. This could not be attributed to any unknown impurity or to overheating of the charges. The average deviation of impact resistance values from a large number of similarly die-cast rods was ±10%. The American specifications could be reached by subjecting the metal to certain heat treatments. The mechanical properties are influenced by the gating cross section, die-casting pres-

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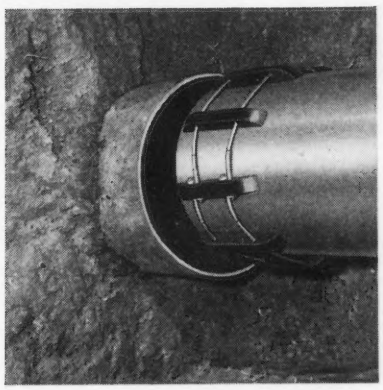

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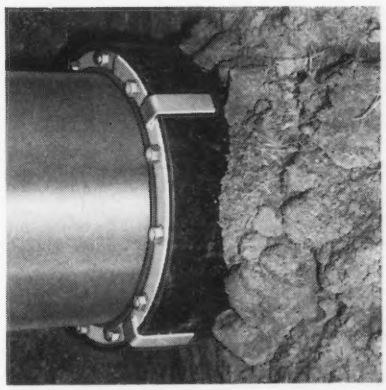

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sure, piston velocity, and chill and bath temperatures. Die casts of age-resistant Zamak 3 were obtained by using very small gate cross sections, namely, 8 instead of 90 mm. Rod samples produced with this modification lost a maximum of 20% of their initial impact strength in the aging test. The mechanical values were not significantly changed by aging at room temperature.

Aging tests were carried out on die casts having the following percentage compositions:

	Alum.	Copper	Mag.	Nickel
Zamak 3	3.7	0.01	0.02	...
Zamak 2	3.9	2.5	0.42	...
Zamak 5	4.1	1.3	0.037	...
Zamak 3N	4.3	0.01	0.034	0.02

Zamak 3 and 3N were inclined to craze unless the die-casting pressure was kept below 80 atm. the chill temperature below 100° C., and the melting bath temperature between 390-400° C. Pressures below 50 atm. caused blistering. These tests included exposure at room temperature, at 95° C., and to watervapor at 95° C. Zamak 3, which according to United States specifications should not age, lost 52% of its impact resistance after a 10-day dry storage at 95° C., and 57% in water vapor at 95° C. The 5% difference was due to intercrystalline corrosion. These losses on aging could not be due to small aluminum and magnesium contents, since the properly alloyed Zamak 3N gave similar values with very small deviations. Zamak 3 lost a maximum of 70% of its impact resistance in both the water vapor and the dry test at 95° C.; in the United States an 85% loss was reported. The impact resistance of Zamak 5 after the first 10-day exposure to water vapor decreased more than in the United States experiments but reached the same value after 20 days. The losses in the dry aging test at 95° C. were equal to those in water vapor; this compares with the 25% decrease in strength reported for American samples. Average deviations amounted to more than 20% with Zamak 3 and to only 13% with Zamak 2 and 5. Illus. tables, diagrs.—DPA.

Korrosionsbestandigkeit von Al-Mg-Mn-Legierungen mit Verschiedenem Kuppergehalt (Resistance to Corrosion of Aluminum-Magnesium-Manganese Alloys with Varying Copper Contents). Vereinigte Leichtmetall-Werke G.m.b.H., Hanover, Ger. Office of Technical Services, PB-73453, Frames 2456-2503 (1944) Nov.

The resistance to corrosion and the aging behavior of KSS alloys with copper contents up to 0.4% depends primarily upon the percentage of copper. A copper content which is sufficiently high to improve aging characteristics decreases the corrosion resistance. The type of attack on areas around a weld seam cannot be expalined by differences in working conditions; the several types of corrosive attack which may occur at other places on the metal, however, are dependent on the annealing temperature. Industrial soft annealing at 400° C. results in an attack which is uniformly distributed and finely granulated; quenching from 500° C. with and without annealing results in flaking; and annealing for 4 days at 540° C. reduces corrosion to a large extent.

Eight different alloys of various copper, magnesium and manganese contents were hot-rolled to 8 mm., then annealed and cold rolled to 3.5 mm. This thickness was reduced by 0, 20, 40, 60, and 80% giving sheets of 3.5, 2.8, 2.1, 1.4 and 0.7 mm. final thickness. Samples of each thickness were soft annealed in the industrial way, namely, 8 hr. at 400° C. and oven-cooled, and others were annealed for 1 hr. at 500° C. in a salt bath and quenched in the same medium. The 0.7 mm. sheets which had received one of these treatments when 3.5 mm. thick were homogenized either for 2 hr. or for 4 days at 540° C. in air and then waterquenched or cooled as follows: at 500, 450, or 400° C. for 1 day, at 350° C. for 2 days, or at 300° C. for 4 days.

The effects of aging at room temperature were also observed on copper-free samples which had been homogenized at 540° C. and quenched; the flow resistance increases markedly after 1 yr. storage, a minimum of 4 mo. being required to show any effects. In most cases a copper content of 0.1% increases the strength of sampels stored for 4 mo.; results show great deviations. Copper contents above 0.2% produce distinct aging effects after 1 yr. in some cases even after 1 mo. at room temperature. Samples which are cooled slowly are not noticeably aged. Samples homogenized for 4 days have a lower resistance to deformation than those homogenized for 2 hr. Samples with copper contents above 0.1% and aged at 125-250° C. for 1-27 days also show noticeable aging.

A DVL stirring test in 3% sodium chloride and 0.1% hydrogen peroxide was carried out for 10-11 mo. When the percentage of copper is plotted against residual tensile strength and yield point the decrease in corrosion resistance is shown to be dependent on both the copper content and on the type of pre-treatment. Samples containing 0.05% copper are only slightly more corroded than copper-free material. Alloys having 0.4% copper are attacked most severely, the degree of corrosion is dependent on the temperature of heat aging. At low temperatures small corroded spots are distributed very densely over the surface, whereas at higher temperatures the attack is concentrated in a few deep pittings.—DPA.

Studies of Dry Corrosion. Oxidation of Magnesium. H. N. Terem. *Rev. Faculte Sci. Univ. Istanbul (Turkey)*, **13A,** 147-159 (1948); *Chem. Abst.*, **42,** No. 20, 7694 (1948) Oct. 20.

The oxidation of magnesium powder and ribbon was studied. A period of induction was noted as in the case of beryllium and aluminum, but only with part of the samples. The catalytic effect of humidity is noted. The "energy of activation" of the oxidation reaction is 23,000 calories per gram in oxygen.—ALL.

Testing Stress Corrosion Resistance of Aluminum Alloys. *Steel,* **123,** No. 19, 121-122 (1948) Nov. 8.

Development of high-strength aluminum alloys for use in larger, heavier and faster aircraft brought new testing problems to the National Bureau of Standards. Tests were conducted in three ways: marine-atmosphere exposure, under stress immersed in a sodium chloride-hydrogen peroxide solution, and under stress in a boiling 6 per cent solution of sodium chloride, the latter test being used only on those alloys containing zinc (R303-T and 75S-T). Unstressed specimens were subjected to the same corrosive conditions in order that the effect of stress in increasing corrosion damage could be evaluated. In the investigations of stress-corrosion resistance flat tensile specimens with ½-inch reduced sections were used under a stress equal to three-fourths of the yield strength. All clad materials were tested with the cladding intact. Losses in ultimate tensile strength and per cent elongation were taken as criteria of corrosion damage. Specimens supported vertically and stressed by means of weighted levers were tested in the sodium chloride-hydrogen peroxide solution (NaCl, 57g, 30 per cent H_2O_2, 10 ml; H_2O, 990 ml), with samples up to 0.064-inch in thickness kept immersed for 24 hours. One-eighth-inch specimens were immersed for 72 hours, the solution being renewed every 24 hours. Specimens were broken in an hydraulic-type tensile testing machine after removal from the solution to determine the tensile properties of the corroded materials. Metallographic examinations were also made to determine the types of corrosion that had developed. For marine-atmosphere exposure tests, the specimens were supported and stressed in a similar fashion, but were then left exposed to the air. Specimens immersed in boiling sodium chloride solution were stressed by bowing. After remaining in the boiling solution for 14 days (unless earlier failures occurred), the specimens were removed, cleaned and broken in tensile tests.

The results of the investigation indicate that flat, bare 24S-T aluminum alloy sheet aged four hours or longer at 375° F (190.7° C) is not susceptible to stress-corrosion cracking in either the laboratory or marine atmosphere tests and is at least as resistant to the combined action of stress and corrosion as the commercially heat-treated but unaged materials. The samples of the other alloys that were tested with the exception of R301-T, were found adequately resistant to stress-corrosion cracking. Failure in the R301-T samples resulted from the penetration of stress-corrosion into the core material at the machined edges of the relatively narrow specimens that were tested. Such damage would not be significant in wide sheets, particularly those cut by shearing.—ALL.

Stress-Corrosion: A Review of the Literature. K. R. Hanna. Division of Aeronautics, Council for Scientific and Industrial Research, Commonwealth of Australia, *Report SM. 120,* Oct., 1948, 10 pages.

Gives examples of the above. Reviews nature of stresses, effects of stress on electrode potentials of metals, alloy characteristics influencing stress-corrosion, methods to prevent or minimize stress-corrosion, and methods of testing.
—BLR.

Electrolytic Corrosion of Steel in Concrete. *Rwy. Mech. Eng.* **122,** 541-3 (1948) Oct.

This subject has been investigated by the Committee on Electrolysis of the Association of American Railroads, as reported at a meeting of the Electrical Section, Engineering Division, in Chicago, Sept. 8, 1948. Cylindrical concrete specimens, each containing a steel electrode, were embedded in the earth and subjected to electric potential. Results indicated that (1) alternating current potential does not corrode the steel; (2) direct current potential will produce electrolytic corrosion of steel in pla

concrete, cracking of the concrete, and deterioration of the concrete if it is in contact with soil containing sulfate ions; (3) for protection the concrete should be surrounded with asphalt membrane waterproofing or the steel should be coated with asphalt; (4) passage of electric current through concrete does not in itself produce deterioration; (5) the use of sulfate-resisting cement will not prevent corrosion of the embedded steel, with resultant cracking of the concrete; (6) the use of admixtures, such as emulsified asphalt, in the concrete mix is not effective; and (7) the use of stainless steel will not prevent concrete deterioration underground if sulfate ions are present in the soil.

Corrosion in Multiple Layer Wound Coils. Howard Orr. *Communications*, **29**, 22-23 (1949) Jan.

Describes progress made in overcoming chemical, electrolytic, and galvanic corrosion, major cause of most open-circuit failures in coils. (To be continued.)—BLR.

Transmission of Cracks from (Electro-) Plate to Underlying Metal. F. D. Rowe and J. B. Dance. *Metal Prog.*, **53**, No. 4, 537-538 (1948).

R. and D. record a case of rapid fatigue failure of a stainless-steel exhaust-valve stem which had been built up, after wear, by hard chromium deposition. Micro-examination showed that pre-existing stress cracks in the chromium plate were linked with fatigue cracks forming in the steel beneath. This case confirms other evidence that hard chromium is an unsatisfactory coating for components operating under conditions of fluctuating stress.—MA.

Note on Stress-Corrosion Cracking of Steels in the Presence of Sulphur Compounds. W. P. Rees. Inst. Metals: Symposium on Internal Stresses in Metals and Alloys, 333-335 (1948); discussion, 463-484.

Reference is made to cases of failures of ferrous materials by stress-corrosion cracking, where the corroding agent was probably hydrogen sulphide or some sulphur-containing compound. Laboratory experiments are referred to which have shown that hardened and tempered alloy steels used for gas-cylinder manufacture are susceptible to stress-corrosion cracking in the presence of moist hydrogen sulphide or carbon bisulphide.—MA.

Internal Stresses in Railway Materials. Hugh O'Neill. Inst. Metals: Symposium on Internal Stresses in Metals and Alloys, 337-349 (1948); discussion, 463-484.

Eighteen examples of the occurrence of internal stress are outlined, in half of which it is deliberately employed to play a useful part. Details are given of manufacturing stresses in various types of rail, and the effect of high-speed pounding by locomotives is mentioned. Values have been determined of the stress in peened piston rings, shot-blasted spring plates, boiler rivets, and expanded boiler tubes. The effect of service straining on stress removal is discussed. Fatigue cracking in axle press-fits is outlined, and the shrink-fits of wheels and tyres are considered in relation to thermal effects from braking and welding.—MA.

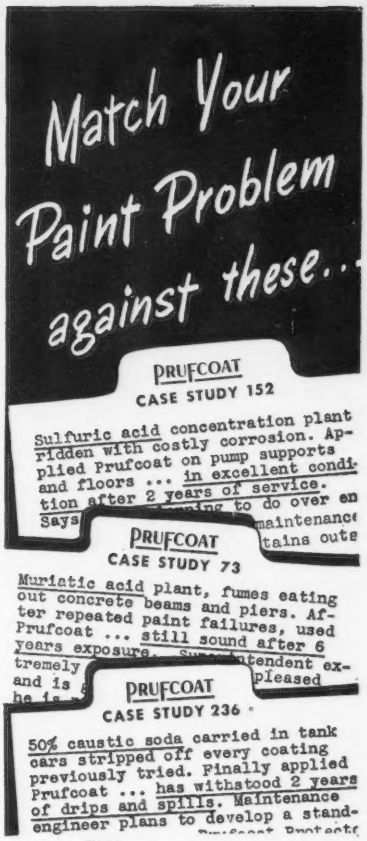
Uber der Einfluss des Reingehaltes auf die Festigkeitseigenschaften und das Korrosionsverhalten von Blechen aus Al (99.0-99.99) und Al-Mg BZW. Al-Mg-Si-Legierung. (Influence of the Purity on the Strength Properties and Behavior Towards Corrosion of Sheets from Aluminum (99.0-99.99) and Aluminum-Magnesium or Aluminum-Magnesium-Silicon Alloys). Schonherr and Geier (Vereinigte Aluminium-Werke A.G., Lautawerk, Ger. Office of Technical Services, PB-70018, Frames 10163-10186 (1941) July.

The tensile strength of hard rolled aluminum sheets of 0.6 mm thickness decreases with increasing purity from 99.00 to 99.99%. This dependence on purity is decreased by adding magnesium and silicon. The addition of 1.5% magnesium is more effective in increasing tensile strength than is 1.5% magnesium plus 1% silicon. Both alloys are less ductile than the corresponding aluminum. The strength of annealed, quenched and aged samples of both aluminum and aluminum-magnesium decreases with increasing aluminum purity; the strength of aluminum alloyed with magnesium and silicon is the same for all degrees of purity. The tricomponent alloy is in all cases stronger than the binary alloy.

The elongation of unalloyed aluminum is higher than the corresponding alloyed samples. The elongation of the tricomponent alloy is least dependent upon the purity of the aluminum. The addition of magnesium gives much lower cupping values than does the addition of magnesium plus silicon. In distilled water the degree of purity of hard rolled and tempered aluminum does not influence its resistance to corrosion. The addition of 1.5% magnesium decreases the corrosion resistance of hard rolled samples in distilled water at room temperature, but the addition of silicon eliminates this loss in resistance. Tempered samples are not adversely affected by magnesium and are improved somewhat by magnesium plus silicon. The resistance of samples which are treated by the EW procedure are independent of both composition and annealing; their weight losses are about ten times lower than those of untreated metal sheets.

In tapwater of pH 6.8 the corrosion resistance of the hard rolled aluminum sheet is dependent on purity. The resistance is not decreased by the addition of magnesium, but it is lowered by silicon, especially in less pure aluminum sheet. Tempering essentially improves the resistance of the aluminum and the aluminum alloyed with magnesium plus silicon. The EW-treatment also improves corrosion resistance in tapwater. The resistance of sheets treated by this method, both tempered and untempered, is not impaired by the presence of silicon.

In 0.5% lactic acid at 20° C the corrosion resistance of hard-rolled aluminum and aluminum-magnesium sheets depends upon the degree of purity of the aluminum. The effect of magnesium is negligible, but that of silicon is deleterious. In the tempered state the influence of purity and of magnesium plus silicon is less pronounced, and the oxidation treatment is ineffective. The addition of 1% sodium chloride to the lactic acid solution increases the attack of the acid, but the various samples otherwise behave as they do in the acid alone. The tempering treatment used in these tests comprised a 3-hr. annealing, quenching from 500° C, and aging at 20° C. The corrosion tests were preceded by a 0.5-hour pretreatment in a 1:5 aqueous nitric acid, followed by a 25-sec. pickling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in 5% sodium hydroxide at 65-70° C, rinsing, neutralizing, and again rinsing. Changes in weight were recorded after 5, 15, and 30 days.—DPA.

Uber den Einfluss der Kaltverformung auf die Spannungskorrosionsbeständigkeit von Al-Zn-Mg-legierungen vor und Nach der Warmaushärtung. (Effect of cold-working on the Stress Corrosion of Aluminum-Zinc-Magnesium Alloys Before and After Heat Hardening.) P. BRENNER AND W. FELDMANN, Vereinigte Leichtmetall-Werke G.m.b.H. Hannover, Ger., Forschungsinstitut. Office of Technical Services, PB-70017, Frames 8852-8864.

Aluminum-zinc-magnesium alloys which are highly resistant to corrosion are produced by carrying out the heat treatment after cold forming; this sequence is also more practical since it is easier to work the material in the cold hardened state.

Stress corrosion tests on heat-hardened aluminum-zinc-magnesium sheet usually consist in plastic bending and elastic stressing of samples taken from the finished heat hardened material. In this heat-hardened state the samples are essentially more sensitive than they are when taken from either cold-hardened or recently quenched material and then subjecting them to bending and stressing tests before a final heat hardening. In the latter case the sensitivity of the alloy is not influenced by different room temperatures during intermediate aging periods between the bending, stressing, and tempering operations; however, if the material has been heat hardened before bending and stressing, the intermediate agings are important. These results are explained in terms of retrogressive processes, release of tension, overlapping elastic residual stresses, and the influence of cold forming upon the segregation processes.

The influence of cold working on the stress corrosion behavior both before and after heat hardening was investigated on loop samples of an alloy containing 4.5% zinc, 2.7% magnesium, 0.6% manganese, <0.2% copper, <0.4% silicon and <0.4% iron. The material was homogenized for 2 hours at 450° C and then aircooled. The order of testing and working operations, i.e., bending, stressing, and heat hardening, was varied with and without intermediate cold hardening during room temperature aging. The annealing times varied between 6 hours and 16 days at 100° C. A 7-day annealing treatment at 35° C was also carried out instead of aging at room temperature.

Stress corrosion tests were carried out for 120 days in a dipping apparatus using artificial seawater. The shortest endurance was found in samples annealed for 2 days at 100° C. This critical annealing period could be offset by adequate cooling treatments, such as stepwise quenching. Only those loop samples which had been stressed after heat hardening were fractured.—DPA.

Versuche Zur Ermittlung des Einflusses der Höhe des Eisengehaltes auf Die Myliuszahl von Aldrey. (The Influence of Iron Content on the Mylius Number of Alfrey.) H. ROHRIG, Vereinigte Aluminium-Werke A.G., Lautawerk, Ger. Office of Technical Services, PB-70016, Frames 6543-6548 (1937) Aug.

The Mylius number of Aldrey containing 0.43 to .02% magnesium, 0.55 to .04% silicon, and from 0.20 to 0.30% iron decreases with a decreasing iron content in the alloy. Since the iron content in unalloyed aluminum does not have this same effect on corrosion it is concluded that the iron exerts only an indirect influence upon corrosion by being involved in the solution and crystallization of the compound Mg_2Si. This role of iron in the solution and crystallization of metallic compounds would be analogous to its action in aluminum-copper alloys where the quantity of iron present influences the processes occurring during tempering.

The Mylius values were determined by exposure to 1% sodium chloride plus 2-3% hydrogen peroxide. The results obtained from two laboratories varied slightly. This may be due to differences in the working of the metals, e.g., in the pressing and rolling operations.

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INDEX TO ADVERTISERS
SEPTEMBER, 1949

Vol. 5 No. 9

	Page
Allied Chemical & Dye Corp., Barrett Division	xi
Aluminum Company of America	x
American Pipe & Construction Co. (Amercoat)	Inside Front Cover
Atlas Mineral Products Co.	28
Brance-Krachy Co., Inc.	xii
Bechtel Corp. & H. C. Price Co.	21
Cathodic Protection Service	18
Cathodic Servicing Co.	Inside Back Cover
Corrosion Engineering Co.	25
M. J. Crose Mfg. Co.	25
Dowell, Inc.	ii
Electro Rust-Proofing Corp.	20
Haering, D. W. & Co.	26
Heil Process Equipment Corp.	24
Huddleston Engineering Co.	16
Humble Oil & Ref. Co. (Rust-Ban)	27
International Nickel Co., Inc., The	xiv
Johns-Manville Co.	vi and vii
Koppers Co., Inc.	23
Leeds & Northrup Co.	viii
J. E. Mavor Co.	30
Mayes Bros., Inc	i
Midwestern Engine & Equipment Co.	ix
Minnesota Mining & Manufacturing Co.	xiii
Mutual Chemical Co.	32
Natasco Co.	34
National Carbon Co.	v
Owens-Corning Fiberglas Co.	29
Perrault Bros.	31
Pipe Line Service Corp.	35
Pittman, Wm. G.	20
Plastic Lining Corp.	40
Prufcoat Laboratories, Inc.	39
Reilly Tar & Chemical Co.	33
Rosson-Richards Co.	18
Service Engineers, Inc.	19
Sims, C. I.	18
Standard Pipeprotection, Inc.	15
Stearns, D. E.	Back Cover
Tator, Kenneth, Associates	18
Thayer, Starr	18
United Chromium, Inc.	17
Wilkinson Products Co.	22
Williamson, T. D.	37

Stress-Corrosion of High-Strength Aluminum Alloys. Nat. Bur. Standards *Tech. News Bull.*, **32**, No. 9, 108-110 (1948) Sept.

Several aluminum alloys introduced during the war, namely the 75S-T, R301-T, R303-T, and artificially aged 24S-T, were studied to determine their ability to withstand the highly corrosive conditions to which military planes are subjected in tropical areas. In the investigation of the stress-corrosion resistance of these materials, standard ASTM flat tensile specimens with ½-in. reduced sections were tested both in the laboratory and in a marine atmosphere under a stress equal to three-fourths of the yield strength. In the laboratory, stressed samples of all alloys were continuously immersed in a sodium chloride-hydrogen peroxide solution. Unstressed specimens were subjected to the same corrosive conditions so that the effect of stress in increasing corrosion damage could be evaluated. All alloys tested, with the exception of R301-T, were found adequately resistant to stress-corrosion cracking.—TDD.

Maximum Temperature of Stability of Various Alloys to Oxidizing Atmospheres. BENJAMIN LUSTMAN *Mat. & Meth.*, **28**, 97 (1948) Nov.

Data are tabulated.

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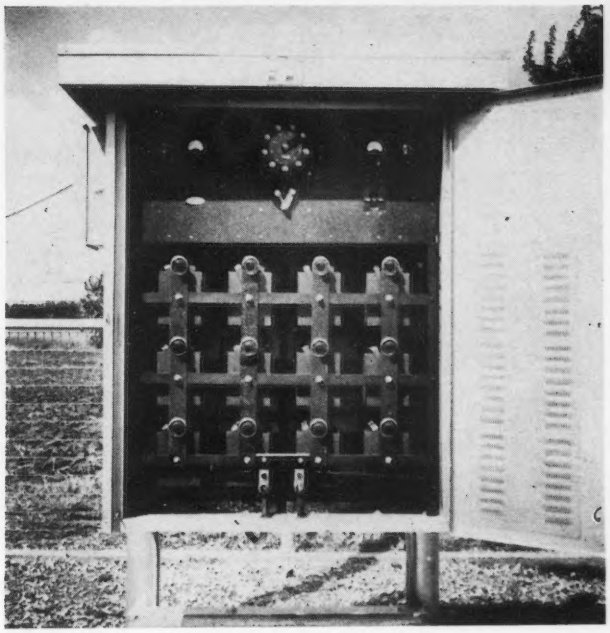

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